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Contents

Applying Synchronous Motors To Main Roll Mill Drives—By L. A. Umansky, Industrial Engineering Department, General Electric Company, Schenectady, New York 1

The Control and Recording of Rolling Mill Pressures—By M. Stone, Engineer, United Engineering & Foundry Company, Pittsburgh, Pa. 21

Circular Heating Furnaces—Their Development For the Heating of Ingots—By M. H. Mawhinney, Consultant, Salem Engineering Company, Salem, Ohio 26

Discussion—Circular Heating Furnaces—Their Development For the Heating of Ingots—Discussion Presented by—M. J. Conway, M. H. Mawhinney, P. M. Offill, F. E. Leahy, A. G. Witting and J. L. Miller 28

Items of Interest 30

Carnegie-Illinois Steel Corporation Executives 38-A

Coming Meetings and Papers III

Editorial V

Index To Advertisers VI

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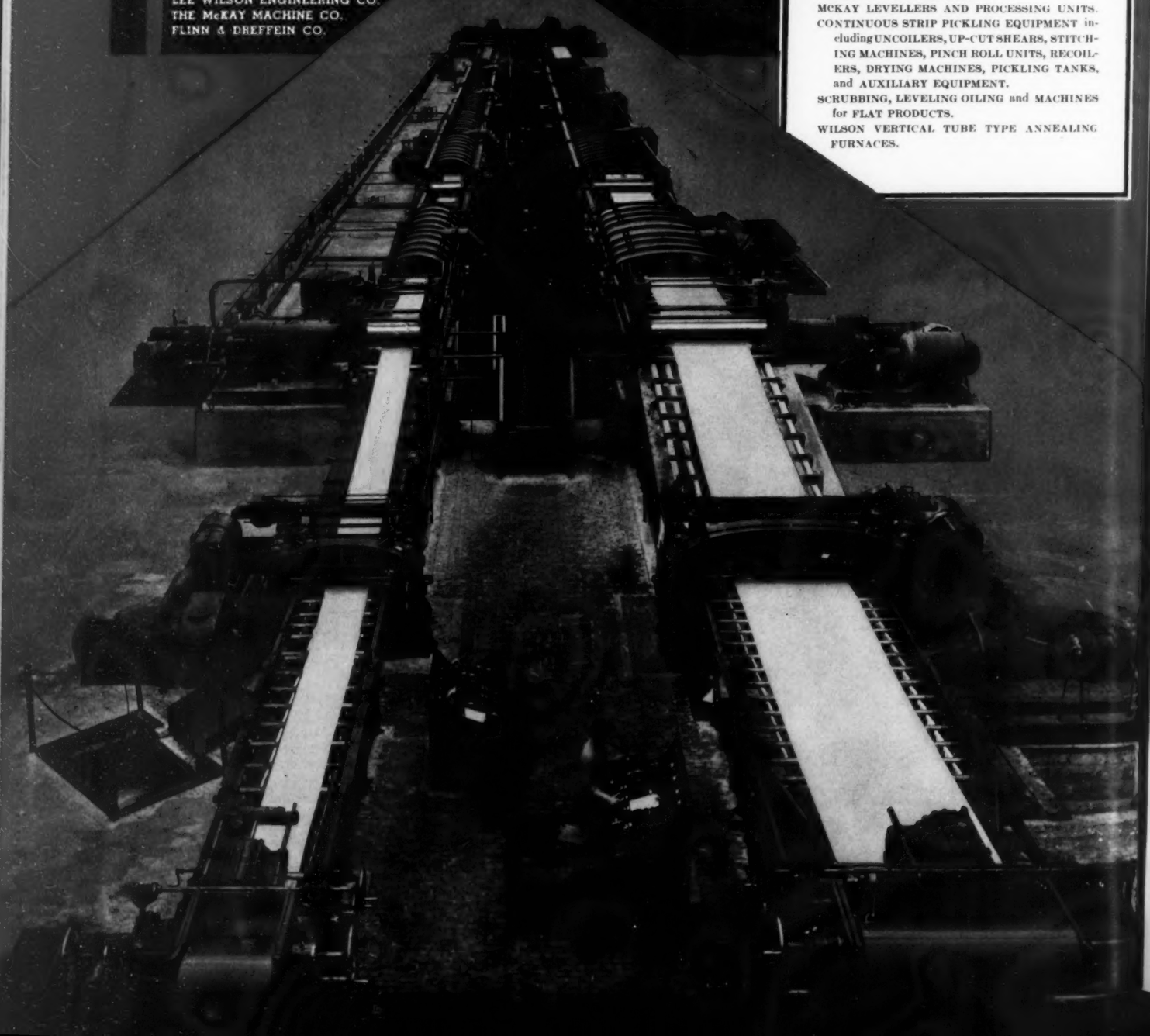


Papers for the Association's 1936-1937 Program

THE TIME has now arrived for the consideration of the yearly program of meetings to be held in the several districts during the period 1936–1937.

While it is the function of the Papers Committee of each district to make the final plans for the meetings regarding subjects to be discussed, authors of the papers, etc., the responsibility for assisting in this work rests with each member of the Association and should be given their earnest and sincere consideration.

The arrangement to secure suggestions regarding subjects to be discussed and the names of the men who are well qualified to present the papers varies in the different sections. One method is to have a preliminary general committee meeting and each member is requested to come to the meeting, prepared to submit a list of specific suggestions. The Paper Committee should in turn solicit all members with the thought of securing their ideas of the most helpful and interesting topics for discussion. This procedure is of particular value in deciding such questions as the advisability of a symposium on a subject as the collective list of subjects would indicate whether or not a particular item is seemingly of general interest and could be discussed from various angles to an advantage.

It is suggested that particular attention be given to papers of an analytical nature. A number of excellent papers have been presented on the subject of hot and cold strip mills, including the topics of general plan of the mill, design of details of equipment, method of operation, etc., Thus far, very little has been written regarding power required for rolling the steel and a paper covering this subject including power required, the thickness and reduction made at each pass, speed of delivery reductions, roll pressure, temperature of steel, etc., would be of great value as a reference. Such an analysis is of particular aid in establishing limiting factors and as a reference it provides a measure of progress as improvements are developed.

It is strongly recommended that more papers of this general character be given consideration in forming the coming year's program.

ADVERTISING PAGES REMOVED

INDEX TO ADVERTISERS

A

Ajax Flexible Coupling Company 82
Alliance Machine Company 84
Allis-Chalmers Manufacturing Company 49
Aluminum Company of America 73

B

The Baker-Raulang Company 86
The Bantam Ball Bearing Company 56
The Bartlett-Hayward Company 78
Bull-Dog Electric Products Company VII
Bussmann Manufacturing Company 34–35

C

The Clark Controller Company 58
The Cleveland Crane & Engineering Company 67
Columbia Electric Manufacturing Company 80
Crocker-Wheeler Electric Manufacturing Company 52
Cutler-Hammer, Inc. ..... Cover 2

D

Dings Magnetic Separator Company 66

E

Edison Storage Battery 64
The Electric Controller & Manufacturing Company 61
The Electric Furnace Company 70
The Electric Storage Battery Company 74
Thomas A. Edison, Inc. 64

F

Farrell-Birmingham Company, Inc. 72

G

General Electric Company ..... 42–43–69 Cover 4

H

Heil and Company 72
Helwig Company 70
Hodson Corporation 41
Hyatt Roller Bearing Company 51

I

Independent Air Filter Company 67
I.T.E. Circuit Breaker Company ..... Cover 3

J

Jefferson Electric Company 40
Johns-Manville Company 36

L

Leeds & Northrup Company 71
Lewis Foundry & Machine Company 65
The Lincoln Electric Company 81
The Lintern Corporation 44

M

The Martindale Electric Company 77
Mesta Machine Company IX
Morgan Construction Company 75
Morgan Engineering Company 59

N

National Carbon Company, Inc. 55–68
National-Erie Corporation 84
New York & New Jersey Lubricant Company 82
Norma-Hoffman Bearings Corporation 60

O

Ohio Electric Manufacturing Company 76
Okonite Company 46

P

Pennsylvania Transformer Company 76
Pittsburgh Rolls Corporation 57
Poole Foundry & Machine Company 54
Pyle National Company 53

R

Reliance Electric & Engineering Company 79
Republic Flowmeters Company 63
Rockbestos Products Corporation 62
Rowan Controller Company 80

S

Schloemann Engineering Company 47
S.K.F. Industries Inc. 39
B. F. Sturtevant Company 85
Surface Combustion Company VIII

T

The Thompson Electric Company 77
The Timken Roller Bearing Company ..... Cover 1
The Tool Steel Gear & Pinion Company 48
Trico Fuse Manufacturing Company 83
The Trumbull Electric Manufacturing Company. 45

U

United Engineering & Foundry Company 38

W

Wean Engineering Company, Inc. II
Wellman Engineering Company 50
Westinghouse Electric & Manufacturing Company IV

APPLYING SYNCHRONOUS MOTORS TO MAIN ROLL MILL DRIVES

By L. A. UMANSKY, Industrial Engineering Department
General Electric Company
SCHENECTADY, N. Y.

Presented before the Cleveland District Section of the Association of Iron and Steel Electrical Engineers

▲ AS NEARLY as the writer was able to determine, the first synchronous motor used for driving a metal rolling mill was the 1350 HP unit installed in 1918 at American Brass Company, Waterbury, Conn.

It was considered then, and for several years to come, as a very freak installation, not illustrating convincingly the adaptability of synchronous machines for this class of service. The synchronous motor at that time was still considered as an inverted generator, maybe suitable for running, once started, but not well adapted for starting a rolling mill.

In the rolling mill practice the induction motors reigned supreme whenever constant speed drives were required. Even in the adjustable speed field they more than held their own, forming part of the Kraemer and Scherbius equipment, thereby intrenching themselves still stronger in the steel industry.

A good many of the constant speed drives were equipped with flywheels;—some rightly so, some merely through the force of habit; the load-slip characteristic of the induction motors made them just fit the flywheel drives.

Then, again, quite a few rolling mills required—as they yet do—a driving motor with a large starting torque. The power systems were, as a rule, much smaller than they are now, so that it was essential to keep the starting current as low as possible. Thus, 10 years ago, the selection of induction motors was justified in, say, 50–75% cases and, through the force of habit, this decision would be generalized and would cover the whole 100% field not leaving any place to the synchronous motors.

The designers of the latter were not dormant in the meanwhile. Synchronous motors were more and more built as motors fully capable of real starting duty. Their squirrel cage winding was not any longer merely a copper amortisseur winding,—but a true starting winding, made of special materials and built with a liberal thermal capacity.

In 2-3 isolated cases additional synchronous motors were applied to rolling mills, but it is the 1925 installation of the 9000 HP synchronous motor at the continuous sheet bar mill of the Corrigan McKinney Steel Co., Cleveland, O., which should be really considered as a landmark from which we should date the history of synchronous motor drives. Since that year and up to the time of this publication the number of these installations grew to 172, with a total installed capacity of close to 300,000 HP. There is hardly left any engineering resistance to this use of synchronous motors. In fact, the tendency is apt to be the other way around, i. e. to attempt to use synchronous motors even in such few cases where their application is questionable. Rolling mills themselves are of too many various types, with entirely different requirements, as far as the drives are concerned. It is therefore both timely and appropriate to review our practice of the past 10 years, to analyze some mistakes made, as well as to formulate the practice which we should now follow, in the light of this experience.

ADVANTAGES OF SYNCHRONOUS MOTORS

Since the slip ring induction motors did their work creditably for a number of years, it is but natural to ask, a question: Why consider the use of synchronous motors at all? What is to be gained by their application?

The first reply is, of course, on everyone's lips: Leading power of the drive itself, ability to correct the power factor of other load. Without this feature it is very doubtful whether we would be discussing the synchronous motor drive today. This feature—leading P. F.—will be covered in more detail in the latter part of this paper.

The second point of advantage is the lower cost of synchronous motors, particularly when low speed drives are concerned. Fig. 2 gives the relative prices of synchronous and induction motors for several ratings. It may be seen that the synchronous motor shines the more, the lower is the speed, the higher is the frequency.

The third advantage—is a more rugged and simpler mechanical design. Salient poles and d-c. field coils are simpler from the standpoint of both the manufacture and maintenance than the rotor winding of a slip ring motor. A larger air gap is another constructional point of advantage, not to lose sight of, especially by the operating men.

The fourth point of advantage—is the somewhat better efficiency of the synchronous motor, particularly for low speeds. A difference of 1-2% is not uncommon.

The fifth feature is the better adaptability of the synchronous motor to a high voltage design. With everything else being equal, a synchronous motor will ordinarily have fewer slots per pole than an induction motor; hence by changing the voltage from, say 6600 V.

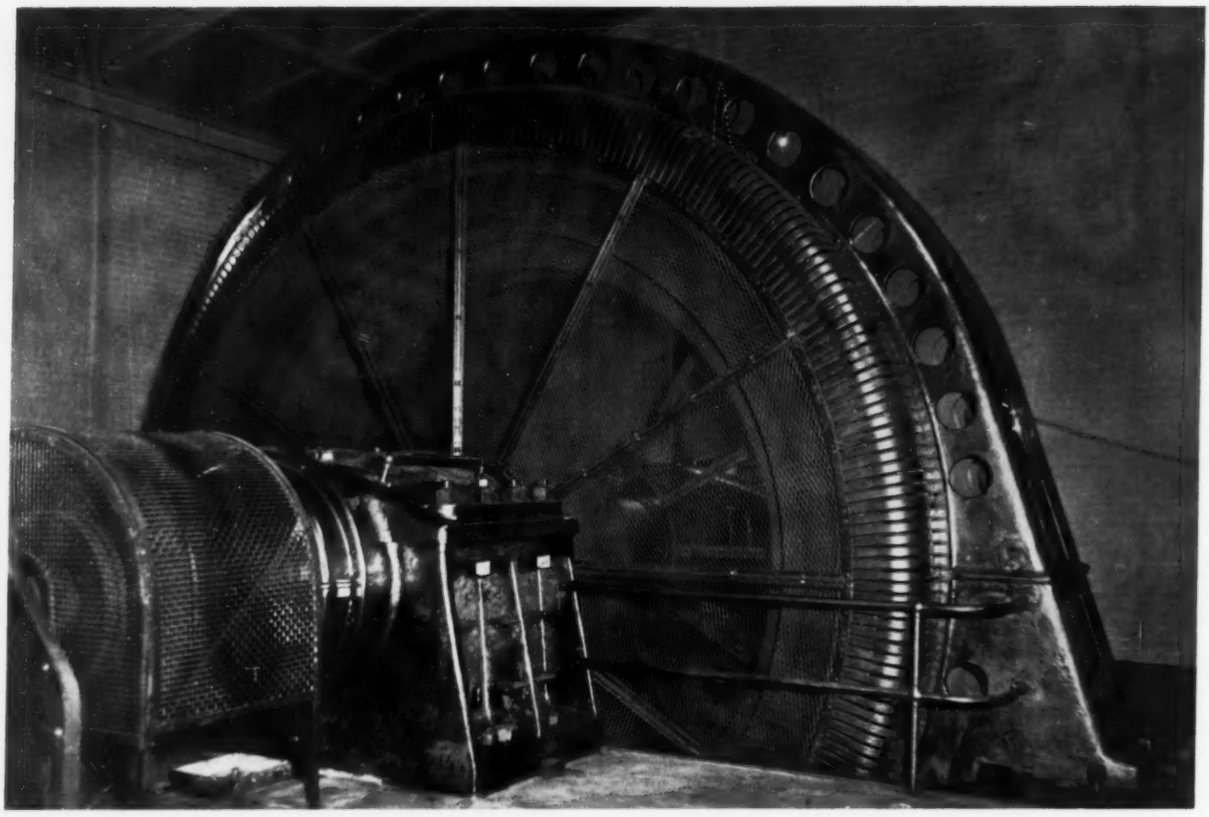


Fig. 1—9000 hp , 107 rpm., 6600 volt, 25 cycle synchronous motor driving the 22.5/19-inch Continuous Sheet Bar Mill of the Corrigan-McKinney Steel Company, Cleveland, O., (now Republic Steel Corporation). This installation opened the era of synchronous motor application to rolling mills.

to 11,000 or 13,200 V., we are apt to increase the physical size and cost of the synchronous motor to a lesser extent than would be the case with an induction machine. By the same token, for a given supply voltage, like 6600 V., it is easier to build a reasonably good synchronous motor of small capacity.

A sixth point should be also mentioned: Contrary to a widely held, but wrong, belief the synchronous motor is less susceptible to voltage fluctuations than the induction motor; the torque of the former drops in straight proportion to the drop of supply voltage, while the torque of the induction motor drops as a square of the voltage.

For very low speeds (like 100 RPM or so) the cost of 60 cycle induction motors and their poor power factor makes the use of geared drives almost imperative. With the synchronous motors the direct, gearless drive has a far better showing.

Finally, for certain mills the true constancy of mill speed, regardless of load, which is obtainable with the synchronous motor drives is of advantage; such is the case, for instance, with continuous mill followed by a flying shear.

All these points of advantage sometimes singly, sometimes collectively, throw enough weight in favor of synchronous motors and bring them into the picture.

To be sure, the synchronous motor has its shortcomings or limitations, too. For instance, any increase of synchronous capacity on the power system tends to increase the magnitude of short circuit currents and, in an extreme case, may cause to either increase the capacity of oil switches or change the power distribution system. There are yet many rolling mills where synchronous motor would be out of place, and these cases will be covered later in this paper.

Assuming now that we are convinced that a synchronous motor application is attractive, let us see what operating characteristics of this machine should be provided, how shall we start and control this motor so as to make a successful mill drive.

CONTINUOUS CAPACITY

The continuous capacity of a synchronous motor drive is determined by the same methods as are applicable to any other type of drive, be it a d-c. or an induction motor. Either a rolling duty cycle is calculated on the basis of a rolling schedule and the RMS-load then determines the size of motor; or the motor capacity is selected by the age-honored rule of thumb, i. e. on the basis of "previous successful installations".

In applying the latter method one has to be particularly careful. A mill, similar to the one which we might be considering, might be equipped with, say, a 2000 HP induction motor with a large flywheel; the peak loads would be smoothed out; the average heating load (the RMS value) would not be more than, say 10-15% higher than the average load, at the most.

Now with the synchronous motor no flywheel will be obviously used; the motor will take the peaks as they come, the motor heating will increase, the spread between the RMS-load and the average load (the latter remains substantially the same) also increases, and a larger continuous capacity of the synchronous motor would be required.

If no flywheel were used on the original mill, then of course the above argument would not hold, and the same continuous capacity of the drive would be required with a synchronous or with an induction motor.

MAXIMUM RUNNING TORQUE

It has been generally accepted as a good practice to specify a maximum running or pull-out torque of an induction motor drive as not less than 250% of the normal, 40°C. rise, rating. This value is usually reduced to 200-225%, in such exceptional cases, when the motor rating is increased to meet the 50°C. rise or when the continuous capacity of the motor is admittedly higher than required. The induction motors seldom have occasion to develop such maximum torque,—unless it is an emergency condition such as a cold bar; the ratio of peak load to the normal rating is usually less than 2:1. One should also remember that the guaranteed maximum torque is obtainable at the rated voltage. If, due to heavy motor load the voltage at the motor terminals drops 10%, then the pull-out torque value of the induction motor drops from 250% to only 202%. Therefore, by specifying a 250% torque we are, indirectly, providing a margin for voltage fluctuations. If higher peak loads than 175-200% are expected, then a flywheel is invariably used and the induction motor pull-out torque does not have to be increased. Hence the same general specifications can apply to practically all induction motor drives, regardless of type of mill.

With synchronous motors the problem is quite different. A motor with a pull-out torque ample for driving a continuous bar mill may not be suitable at all for a tube piercing mill. Hence it would be wrong to issue a standard set of synchronous motor specifications in the vain hope that they will cover all cases.

The first column of the enclosed Table I suggests the values of pull-out torques which are believed to be reasonable and ample, if any of the listed mills is to be synchronous motor equipped. Exception might and will probably occur, hence the given torques should be used merely as a guide, while each individual case should be studied and analyzed.

The table shows that only in few cases it is advisable to go below 250% normal (on the basis of 40° rating); in some instances it is recommended to go to pull-out torques up to 300% and even 400%-500% normal.

The most natural question to ask, is this: What does it mean to motor size and cost? Is it necessary to increase the continuous capacity of the motor, and to pay more for it accordingly, just to get an extra high value of maximum running torque? Or can this value be obtained by more economical means?

It may be stated with a large degree of accuracy, that if a synchronous motor were designed most economically, just to meet the heating requirements, then

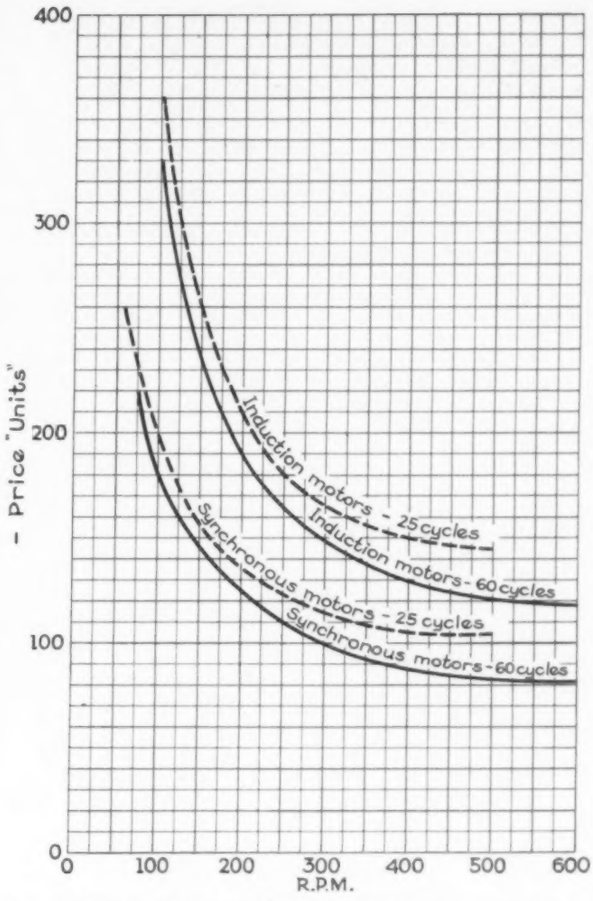


Fig. 2—Relative Costs of Mill Type Synchronous and Induction Motors, 60 and 25 cycle. The costs cover motors only, without switchgear, control or exciters.

the following maximum running torques would be obtainable:

.8 P. F. motors—225% normal (on 40° basis)
1.0 P. F. motors—150% normal (on 40° basis)

In order to obtain higher pull-out torques, the motor must be made larger in diameter, or in length, or in both. In other words the maximum torque determines in this case the physical dimensions of the machine.

Suppose for instance, we want to build a drive with 2000 HP continuous rating and with a 7000 HP pull-out torque (350% normal). The machine will be designed on the basis of this maximum torque. What continuous rating shall we give to this machine? Shall we call it 2000 HP, with 350% pull-out torque, or 3000 HP with 233% pull-out torque, or something else? What are the engineering or economic reasons for one policy or the other?

In the first place, the 3000 HP rating would naturally call for more copper; this in itself adds something to the cost. But the main point is that this additional copper will require larger slots; this in turn will cut down the maximum running torque. In other words, the motor dimensions would have to be still further increased to maintain the 7000 HP torque.

For one given maximum torque it is usually easier to build a motor with a lower continuous capacity.

In our example it is more advisable to leave the rating as 2000 HP instead of boosting it to 3000 HP, if the extra 1000 HP are really not needed. The cost per HP would be of course lower with the 3000 HP rating, but the total cash outlay for the drive will be kept lower on the 2000 HP basis. On the other hand it is also obvious that in this case the cost of the extra 1000 HP would be less, than the cost difference between a 2000 HP and 3000 HP drives, with the same percentage of maximum torque in either case.

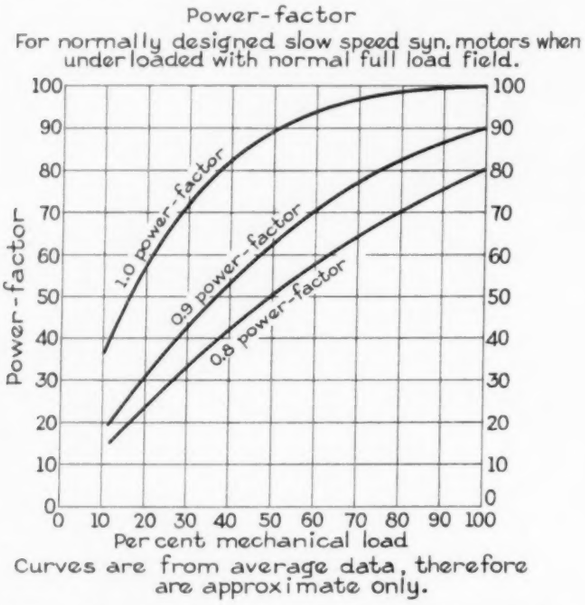

Power-factor
For normally designed slow speed syn. motors when under loaded with normal full load field.
Power-factor
1.0 power-factor
0.9 power-factor
0.8 power-factor
Percent mechanical load
Curves are from average data, therefore are approximate only.

Fig. 3—Power factor of Synchronous Motor designed to give 1.0, 0.9 or 0.8 power factor at rated load, and operating with constant excitation at various mechanical loads.

It is also possible sometimes, when abnormally high pull-out torques are required, to obtain these values not by "brute force" alone, i. e. by going to a larger size machine,—but by artificial means such as overexciting the motor during the short time intervals when high torques should be exerted. These methods will be presently discussed.

OVEREXCITATION UNDER HEAVY LOAD

In a synchronous motor, like in any other electrical machine, the developed torque is proportional to the product of current and magnetic flux.

When a heavy load is imposed on the synchronous motor, the demagnetizing action of the stator current reduces the magnetic flux of the machine. This flux should therefore be so proportioned, to begin with, that enough of it be left under heavy load to provide sufficient torque to resist the load.

Now it may be asked: If the abnormally high peak loads, like 300% or 350% are few and far between,—say they occur 3-4 times a day, and last only few seconds at a time—is it correct to design and build a very much oversized motor, with a very large built-in flux, just to take care of these infrequent peaks, and to run this more expensive motor, with greater losses, for several thousand hours a year? Can we provide control means to automatically increase the motor excitation when the load is abnormally high, to offset the demagnetizing action of the stator by creating temporarily extra ampere-turns of the field winding? The original flux will be then maintained, and a smaller motor will be then capable of developing larger maximum running torques.

This point is well taken and deserves a careful study. It ordinarily takes a few seconds to build-up a magnetic flux of a large machine. Likewise, the magnetic flux cannot be reduced instantly. Therefore, the synchronous motor can more readily withstand a heavy peak of very short duration (fraction of a second), than a sustained peak of the same magnitude, because in the latter case the stator reaction has time to back down the magnetic flux. In other words, the "transient pull-out torque" is higher than the "steady-state pull-out torque"; the difference may be 20-40% for low speed machines and as high as 60% for high speed motors.

Now, suppose we desire to maintain the value of transient pull-out torque and not let it die down to the steady-state torque. This means that we shall not change the magnetic flux; on the contrary we will oppose the change. Therefore we do not have to overcome a magnetic inertia: the ampere-turns can rise as quickly as the control devices can respond to the the changes of load. If we can do so successfully then

TABLE I

TYPICAL TORQUE REQUIREMENTS OF METAL ROLLING MILLS—TO BE USED AS GUIDES IN THE APPLICATION OF SYNCHRONOUS MOTORS

Torques are given in percentage of normal torque at 40 deg. C. continuous rating.

Starting torques are the values that must be obtained *at the starting voltage.*

Values given are merely typical; individual mills may require higher or lower torques.

Type of Mill	1 Maximum Running or Pull-out Torque	2 Starting Torque at Starting Voltage	3 Pull-in Torque at 95% Speed
Blooming and slabbing mills, 3-high	250–350%	35%	25%
Structural rail roughing mills	250–350%	35%	25%
Structural and rail finishing mills	250%	40%	30%
Plate mills	250–350%	35%	25%
Merchant mill trains	250%	60%	40%
Billet, skelp and sheet bar mills, continuous with lay shaft drive	250%	40%	30%
Rod mills, continuous, with lay shaft drive	200–250%	75%	40%
Hot strip mills, continuous, individual drive	250%	25%	20%
Tube piercing and expanding mills	250%	40%	30%
Tube rolling mills	300–350%	40%	30%
Tube reeling mills	250%	60%	40%
Hot sheet and tin mills	300–500%	125%	100%
Cold sheet and tin mills	250%	200%	150%
Brass copper roughing mills	250%	50%	35%
Brass copper strip finishing mills	250%	150%	125%

our previous reasoning is correct and a higher value of pull-out torque can be obtained out of a given size of motor by means of "overexcitation under load".

Various means were suggested and applied for this purpose—and with various degrees of success. One of the earliest arrangements, consists substantially of the following. Excitation is taken from a 250 volt excitation bus, but the motor field is laid out for a lower voltage, say 150 or 175 volts; a balast resistance is inserted in the field circuit. A contactor, actuated by a load relay in the stator circuit, would short circuit this resistor, if and when an abnormally high peak load would be imposed. 99.99% time the motor would run with the resistor cut in; the pull-out torque with normal excitation would be say 250% or less, but with the contactor closed—the torque would go, say, to 300% or more. In this manner a smaller motor could be used, which would have lower cost and lower losses. Part of this possible saving in losses would be, of course, lost under the described arrangement in the balast resistor. It takes a fraction of a second for the load relay to pick up; another fraction of a second is required by the contactor to close; not less than .25 second should be allowed for these two devices to function.

If the synchronous motor is provided with a separate exciter then an attempt is apt to be made to control the motor excitation through the exciter field. Balast resistor and its losses would be then eliminated. The arrangement is, again, workable in certain cases, but it is obvious that more time elapses between the cause and the result; the exciter field and voltage do not respond instantly to the load relay or its equivalent. Between 0.5 or 1.0 seconds should be allowed to make this control effective. Special exciters with a very high rate of field build-up can be designed and applied—as it has been done with large synchronous condensers operating on some transmission lines. Such exciters are, of course, expensive, while the main purpose of all these schemes is to save some money, by cutting down the size of the motor. If most or all of this saving is spent on an elaborate control equipment, exciters, etc., —it is questionable whether such engineering solution is sound.

Finally, a number of factory tests point out that highly satisfactorily results may be obtained by use of thyration tubes to control the field of the synchronous motor. But this has not been as yet reduced to practice on any steel mill installation.

Now we have to analyze how rapidly the rolling mill load increases to a very high value like 350% normal. If the increase takes place in a very short interval of time, like .25 sec. or less, then the devices controlling the "overexcitation" will function when it might be already too late; i.e. after the motor had already pulled out of step; i. e. when it is more proper to remove the excitation rather than to increase it.

Here again, it is wrong to generalize, and various mills should be studied individually.

For instance we may have a continuous bar mill. We are all familiar with the load curve of such a drive: As the front end of the bar passes from stand to stand, the load gradually increases, step at a time, until a steady peak is reached. Now assume that the bar is colder than usual; each load increment will be therefore larger than it normally is; the load relay setting will be reached a few seconds before the bar reaches the last stand and the overexcitation will have ample time to take place before the cold bar is in all stands simultaneously and produces a load which would be greater than the pull-out torque of the motor with normal excitation.

Rod mills, many merchant mills and few others also fall into this class, as far as the character of load build-up is concerned. In such cases the use of the over-excitation method is practicable and may be considered, if otherwise desirable.

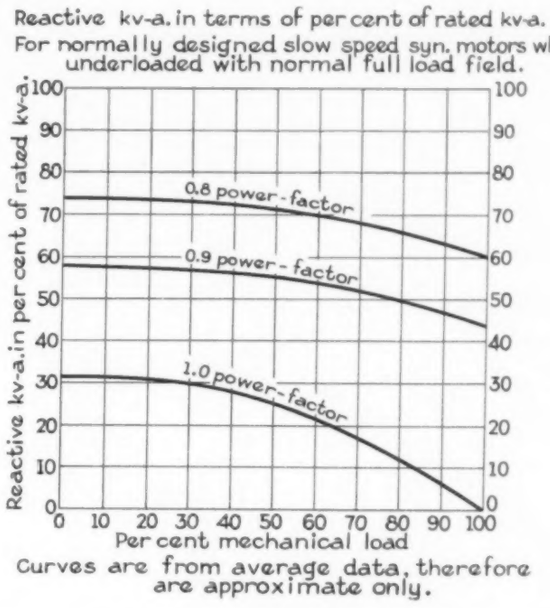

Reactive kv-a. in terms of per cent of rated kv-a.
For normally designed slow speed syn. motors when underloaded with normal full load field.
Reactive kv-a. in per cent of rated kv-a.
0.8 power-factor
0.9 power-factor
1.0 power-factor
0 10 20 30 40 50 60 70 80 90 100
Per cent mechanical load
Curves are from average data, therefore are approximate only.

Fig. 4—Leading kv-a. (available for power factor correction) of synchronous motors, designed to give 1.0, 0.9 or 0.8 power factor at rated load, and operating with constant excitation at various mechanical loads.

A 3-high plate mill, if directly driven by a synchronous motor, would be at the other extreme end of the scale. The slab or plate, entering the rolls, imposes a sudden peak load; if the peak is higher than the motor pull-out torque, then the load control devices may not have enough time to function.

To the same class belong also the Hot Sheet & Tin Plate Mills. It is true, that by the "law of probabilities", the several bars or packs do not ordinarily enter their respective stands simultaneously; but once in a while this does take place and the motor should either take the load with its normal excitation, or fall out of step. Synchronous motors were built to withstand even this severe class of service.

In a class by itself are to be found synchronous motor-generator sets for reversing drives. The latter are well known by the high peak loads encountered; a bloom, or a slab enters the rolls, and the reversing motor torque rises very rapidly. However, the entering usually occurs at a relatively reduced speed; the latter is gradually increased with the metal in the rolls. Thus the HP peak load (and the synchronous motor

of the set "feels" this load and not the "torque-load" of the reversing motor) rises more gradually and time is usually available to successfully apply the over-excitation, if this is needed.

As a matter of fact the idea and the practice of overexciting the synchronous motors of the sets, as a function of load, is at least 25 years old. In railroad practice the sets are conventionally guaranteed to carry peaks up to 300% normal. The synchronous motors of these sets are provided with separate exciters; the latter have one field winding to furnish the basic excitation (corresponding, say, to 1.0 or .9 P. F. at no-load) and a compounding winding through which flows the armature current of the main D.C. generators (the latter operate at substantially constant voltage). In this manner the compounding of the synchronous motor proceeds automatically and quite successfully.

There is no good reason why a similar scheme could not be applied, with suitable changes, to a reversing mill equipment. Or, if preferred, a load relay or a load control regulator responsive to the A.C. load, could be very well used. An analysis recently made by the writer in connection with a 40-inch reversing universal plate mill seems to indicate that by applying the compounding principle to the synchronous motor of the set, the capacity and cost of the latter might be substantially reduced; the average losses are reduced by some 30 KW and this might result in 3—5% reduction in total power consumption.

Summing up, we may state that the overexcitation or compounding is an effective device if judiciously applied. But it is apt to cause trouble, by failing to act when expected, if it is misapplied.

Another idea is sometimes advanced, prompted by the same desire: not to increase unduly the size of the motor on account of the maximum peak load. The idea is simple enough: If an exceptionally high peak load will come once in a great while—let the motor pull out of step. Suitable control devices will remove the excitation and, when the abnormally high but short peak passes, the devices will automatically re-synchronize the motor.

There is nothing wrong with this arrangement, provided it is rightly used. That is, it is nice to have on hand such control to take care of only those peak loads which are even higher than the maximum expected ones. In other words, the falling out of step and re-synchronization should be an emergency condition and not part of the regular mill performance.

Therefore the overexcitation and the re-synchronization methods do not really oppose or contradict each other. They partly overlap but mainly supplement each other.

POWER FACTOR

A "good" power factor is inherent to a synchronous motor. It is either a "leading" one, with some corrective KVA available even when carrying the rated mechanical load, or a "unity" P.F., not providing under full load any leading KVA, nor taking any lagging KVA from the line. In other words the synchronous motor can correct the plant's power factor directly, by offsetting by its own leading KVA, the lagging KVA imposed on the system by induction apparatus or, even if it is an unity P.F. machine, it still improves the total P.F. because to the "bad P.F." load it adds its "good P.F." load, so that the total P.F. will be nearer unity.

It is well known from the general theory of synchronous motors that if it were desired to maintain the same P.F. at all loads, it is necessary to increase the excitation when the load increases and vice versa. In the greatest majority of cases this is not done; the excitation is adjusted to give the rated P.F. at the rated load and then the motor is left running throughout the range of loads with constant excitation. This means that we obtain some extra corrective KVA when the load is light and somewhat less than the rated amount of corrective KVA at overloads.

Two curve sheets were prepared (Figs. 3 & 4) illustrating this performance. These curves give the available corrective KVA and the P.F. at various % of mechanical load for synchronous motors, having .8, .9 and 1.0 power factors. These are only typical, average curves and should be considered only as such; the reader is warned against their use as if they were strictly correct for all specific cases.

With these general characteristice clearly understood we may approach our next problem: For what P.F. to build a synchronous motor driving a mill, once its HP is given? There are two ways of approaching this problem: 1, to analyze the effect of different P.F. on the motor itself and 2, to consider the motor P.F. as part of the power system characteristics.

Generally speaking, a .8 P.F. motor is larger and more expensive than a 1.0 P.F. motor of the same HP rating. This is what would be expected, because the stator winding of the first motor must not only carry the power corresponding to the mechanical shaft output, but also the corrective KVA; likewise the field winding of the first motor has more capacity because (as is well known) the synchronous motor must be overexcited to operate at a leading P.F. In other words, a .8 P.F. motor is bigger all around, and should cost more.

Just because it is bigger for the same shaft HP rating it is inherently capable of carrying higher mechanical peak loads than its 1.0 P.F. counterpart. Its pull-out torque is higher. We have already noted that a .8 P.F. motor, built with the heating as the only limit (40°C rise), is usually capable of carrying peak loads up to 225% normal; an unity P.F. motor, under the same circumstances, will be good only for about 150% load.

Now, for a mill drive, as we know, a pull-out torque of 250% normal or more (on 40°C rise basis) is ordinarily required. Therefore the above .8 P.F. motor should be slightly increased, and the 1.0 P.F. motor should be increased quite appreciably in order to obtain this pull-out torque value; when this is done there will be very little difference in physical dimensions (and also in the cost) of the two machines. It is even conceivable that in certain cases it will be somewhat easier to build a .8 P.F. motor for a 250% pull-out torque than a 1.0 P.F. motor. The higher is the Pull-out Torque requirement,—say 300 or 350%,—the more advantages there will be found to build a .8 P.F.

Fig. 5—Hig
360 rpm., 6
Mill of the

machine; it might actually cost less than a unity P.F. motor with same pull-out torque. And, of course, we will get the advantage of some corrective KVA which may or may not be useful to us.

In other words, as far as the mill motor itself is concerned, we do not ordinarily increase its cost perceptibly by calling for a .8 power factor. And now let us check the effect of the motor P.F. on the power system of the steel plant.

If the present system has a low P.F., then of course, the answer is obvious, the new synchronous motor should be, by all means, ordered with a leading P.F. say .9 or even .8, because we get the corrective KVA for practically no expenditure, as long as a high pull-out torque is specified. When the synchronous motors were first applied to main drives, the power factor of most systems could always stand some improvement because the other constant speed mills were driven by induction motors; thus 80% P.F. motors were ordinarily specified,—and rightly so.

But the more such drives are installed, the less need there is for any further power factor correction. Then, again, the adjustable speed drives are now practically monopolized by D.C. motors supplied with power from synchronous M-G sets. As the result of this condition several steel plants, with the equipment on hand, could operate with a leading P.F. of the whole system.

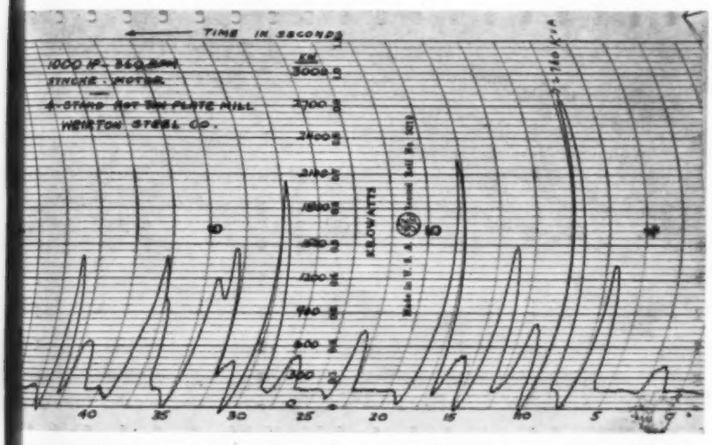


Fig. 5—**High speed Wattmeter chart recording the input to a 1000 hp., 360 rpm., 6600 volt synchronous motor driving a 4-stand Hot Tin Plate Mill of the Weirton Steel Company. This class of service requires a motor with a very high pull-out torque.**

Now, excessive leading KVA are just as bad for a power system as excessive reactive KVA; power house generators sometimes operate underexcited on that account; the voltage regulation of the system becomes very unsatisfactory. If this is the case then it is wrong to *always* call for .8 P.F. motors. It might be then advantageous, from the broader standpoint, to order a motor with the same pull out torque, but designed to run at a unity power factor.

REQUIRED STARTING CHARACTERISTICS

General Definitions

A synchronous motor, when being started, is not, and does not act as, a synchronous machine at all, but as a rather poor squirrel cage induction motor. Hence its starting and running characteristics may be said to exist almost quite apart from each other; figuratively speaking, the synchronous motor has a "dual personality" in this sense.

Let us define the normal running torque of the motor—as a 100% torque, and the corresponding KVA input—as a 100% input; thus the ratio of torque to input is assumed to be then 1:1, or also 100%.

Now, when the machine is started as a squirrel cage motor, with full voltage applied to the stator winding, the ratio of the starting torque (expressed in per cent of normal running torque) to the starting KVA (also expressed in per cent of normal KVA) is usually much less than 1. This ratio, most appropriately called the "torque efficiency" of the motor, is usually around 25-30% for an average 60 cycle motor of conventional design and is 40-50% for 25 cycle machines. In other words, to obtain a given starting torque out of a synchronous motor, we must be ordinarily content with a 3-4 times as large a KVA input per unit of torque, as we do under normal running conditions. In this respect the synchronous motor is far inferior to the slip ring induction motor which may be readily given a starting torque efficiency of 100%. Furthermore, the power factor when starting a synchronous motor is quite low, say around 30%. This is due to the relatively large air gap and therefore to the large magnetizing current; also due to the greater leakage reactance on account of fewer slots per pole. On the other hand the starting power factor of a slip ring motor is comparable with its power factor at the rated load.

The starting current inrush is practically limited by the motor reactance; we would call this reactance 100% if the starting current at full voltage were 100%. With a lower reactance like 50%, 30%, 25%, etc., the starting current will be 200%, 333% or 400% respectively. The starting current as defined, corresponds, of course, to the sustained value with a blocked rotor.

As the motor accelerates, its slip decreases, and when approaching synchronism, the "induction motor torque" rapidly falls off; at synchronism this torque is, of course, zero, like is the case with any induction motor. The motor, even running light, should always exert some torque,—to overcome the friction, windage and other losses. Thus the "induction motor torque" is inherently incapable of bringing the machine in synchronism.

However, the presence of salient poles changes the picture when the motor has accelerated to its almost synchronous speed; the rotating field of the stator tends to bring the salient poles of the rotor "in step" with its own (stator field's) imaginary poles, rotating of course at strictly synchronous speed. Depending on the amount of external load, inertia of rotating parts, and the force of attraction between the stator and rotor poles, this "pulling-in step" may actually occur at, say, 95% or 97% or 98% of synchronism, as the case might be. The smaller is the slip, the longer is the time interval during which the rotor pole passes under the corresponding stator pole, and the torque, due to the attraction of poles (the so-called "salient pole effect" or the "reluctance torque") may have a

chance to accelerate the rotor from, say, 95% to 100% speed. But if the WR^2 of the system is high, or if the external load is heavy, or if salient pole effect is rather weak,—then it is necessary to first accelerate the motor from 95% to, say, 97%, or 98% speed before this salient pole torque will succeed in pulling the machine in step.

If excitation is applied, when conditions are favorable, it has the effect of very materially increasing the attraction between the stator and rotor poles; then the available synchronizing torque will help the motor to pull in step even with a heavy load or high inertia. But a premature application of field, (i. e. when the slip is yet high) would back down the induction motor torque which tends to accelerate the motor; the rotor poles are slipping past the stator poles so fast, that it is out of question to accelerate and to pull-in step the heavy inertia load in the short time available.

Thus the function of the induction motor torque is to accelerate the motor to a speed so close to synchronism ,that the salient pole effect (reluctance torque) or the synchronizing torque of the excited motor is capable of doing the actual work of pulling the motor with load into synchronism.

Although this process is well understood by engineers, the accepted definition of pull-in torque applies to the "*induction motor torque at 95% synchronous speed*". This is not a very good definition, in the writer's opinion, because it describes as a "pull-in torque"—a torque which does not do the actual pulling-in step; but pending the change of the accepted term, we may just as well remember what this term actually stands for.

In the greatest majority of steel mill drives, the inertia (WR^2) of the mill is low, and the running friction load is light, so that the salient pole effect, without any excitation, is usually sufficient to pull the machine in step. The motor then runs at a strictly synchronous speed but with a very low power factor as the motor is rather "under-excited". If the inertia or the friction load were high, then the field application would be essential to pulling in step. Such is the case for instance with pump or compressor drives, some cement mill drives and like. The synchronizing torque of an excited motor is then comparable in magnitude with the running pull-out torque.

Mill Requirements

First of all, let us try to analyze how much of a starting torque we actually need for a rolling mill. Again, the mills differ so much from each other, that it is impossible to set a general rule. Instead of this, the columns 2 and 3 of the Table I are offered as a practical suggestion; most of these values are based on tests and other practical data obtained on existing installations. The torque values given in the tabulation are believed to represent the most severe starting conditions for an average mill of each class; in many instances lower starting and pull-in torques might suffice; likewise it is conceivable that more difficult cases might come up in the future.

It will be noted that with the exception of sheet and tin plate mills and certain brass and copper mills, the required starting torque is usually less than 60% normal. In a greater majority of cases (and this usually happens when the synchronous motors are otherwise well suited to the mill drives), the starting torque requirements are only 35-40% normal (or less); it is assumed that the mills are not overmotored, i. e. the "normal"—is the rated torque of a well selected, 40°C rated motor. If the drive is 50°C rated, i. e. if the nameplate HP rating of the same motor has been increased by some 15%, or when the mill is admittedly overmotored, then the torque percentages may be suitable reduced.

In computing these tabulations we have assumed that the mills will be started from rest without any metal in the rolls; the mill friction (on a cold winter morning) is supposed to be the only load to overcome. Once the motor breaks the mill loose, the value of friction drops down. Therefore the minimum pull-in torque value required to synchronize the motor, or to pull it in step, when approaching synchronism, is always somewhat lower than the starting torque (see column 3 of the Table I).

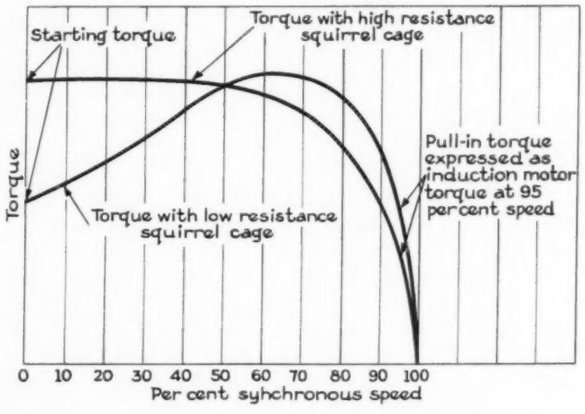

Starting torque
Torque with high resistance squirrel cage
Pull-in torque expressed as induction motor torque at 95 percent speed
Torque with low resistance squirrel cage
Torque
0 10 20 30 40 50 60 70 80 90 100
Per cent syhchronous speed

Fig. 6—By varying the resistance of the squirrel cage (starting) winding, the starting and pull-in torque values may be re-adjusted in relation to each other.

Experience has also shown, that certain mills with closed passes, are much harder to start empty after an extended shut down if the rolls were left tightly set to maintain the gauge. Such might be the case with rod mills; as much as 70-80% starting torque might be required if all rolls remain tight and the mill was left standing for a day or so. But if the roughing stand rolls are loosened up then a 60% torque is quite ample, as the tabulation shows. It is advisable therefore to provide a normal starting torque for such drive, but have means to develop, in emergency cases, the maximum, full-voltage starting torques.

We should also remember that the motor torque is estimated at normal line voltage. If the high starting load is apt to pull this voltage down, the available motor torque is cut down as the square of the voltage.

But let us suppose that the power went off during the rolling operation, with the bar left stuck in the rolls. A continuous bar mill may serve as a good illustration of such an accident. Will it not be necessary to re-start the mill with the metal in the rolls and will

not the then required torque be larger than the "cold friction" torque given in the tabulation?

In the first place no one will attempt to restart the mill in the rolling direction after the described incident. This would ruin the rolls. An attempt will be made to back the mill out, prefereably with loosened up rolls. In case of a continuous mill, the bar is ordinarily cut by torches between the stands so that the backing out travel is quite short, and there is no need to synchronize the motor under circumstances.

The practice has shown that this performance does not increase the minimum requirements for the motor starting torque, and does not enter at all in selection of the pull-in torque.

The sheet and tin plate mills, particularly when engaged in cold rolling are the "hardest nuts to crack". Large mill friction; presence of a drag; tight setting of the rolls; all this makes the starting problem quite difficult for a synchronous motor, particularly if the starting KVA are to be limited.

If we also remember that with these mills the peak loads are quite high with reference to the normal rating, then we may rightly relegate the sheet and tin plate mills to the bottom of the list of desirable applications of synchronous motors.

With these mills excepted, it should not be considered very difficult to design and build synchronous motors with starting and pull-in torques of required values.

Obtainable Motor Starting Torques

Since we know, or have at least assumed the starting torque requirements of the various mills, let us find out what starting torques can be readily obtained with the synchronous motors. Is there any relationship between the continuous or the pull-out torques on the one hand and the starting and pull-in torques on the other hand?

Let us, first of all, point out that for a given motor we may vary within certain limits the starting torque at the expense of the pull-in torque, and vice versa by changing the material (and therefore the resistance) of the starting, squirrel cage winding; say, for instance, the starting torque is 80% and the pull-in torque is 60%; if we increase the squirrel cage resistance we may succeed in raising the starting torque to 90% but will probably reduce the pull-in torque to, say 50%, maintaining about the same average between both values. This is, of course, only a very rough approximation and should be taken as merely indicating the general trend. Fig. 6 illustrates this point graphically.

For rolling mill motors it is always more essential to have a larger starting than a pull-in torque, because as we know the static mill friction is always higher than the running friction.

The lower is the motor speed, the more poles it has and the greater is the motor reactance. This reactance cuts down both the starting current and the starting torque. Therefore a low speed motor is apt to have—everything else remaining equal—a smaller starting torque expressed in % of normal than a high speed motor of same rating.

What is "low speed' for a 100 HP motor may be considered as medium or even "high speed' for a 5000 HP machine. Therefore, for one given motor speed or number of poles, a large capacity motor is apt to have a higher % starting torque than a smaller capacity unit. A statistical study of the subject (carried out in April 1929 by Mr. H. D. Taylor, A. C. Engr. Dept., General Electric Co.) shows that a fair "index number" of this characteristic is proportional to the square root of the HP and inversely proportional to the number of poles; in other words, this number

$$X = \frac{\sqrt{HP}}{\text{No. of Poles}}$$

For instance, for a 2000 HP, 150 RPM, 48 pole, 60 cycle motor

$$X = \frac{2000}{48} = \frac{44.8}{48} = .93$$

This index number will be helpful to us when using the torque curves to be presently explained.

Finally, there is a certain obvious connection between the values of the pull-out torque and the starting torque. A motor with a large pull-out torque is an oversized machine, in relation to its normal torque. It is but natural therefore that for a given continuous HP rating, the motor with a high pull-out torque will also have a higher starting torque.

The curve sheets, Figs. 7, 8, 9 and 10 illustrate these characteristics of 0.8 and 1.0 P.F., 60 and 25 cycle motors. Here again we must realize that these curves merely indicate the general trend and should not be taken as a strictly mathematical expression.

Let us see what these curves can tell us. Suppose we take again the 2000 HP, 150 RPM, 48 pole motor with an .8 P.F. The "index number" of this motor was already determined as .93. Let us find the point A = .93 on the horizontal ordinate, of Fig. 7, and draw there a vertical line A-B. If crosses several curves, each representing a value of a pull-out torque, and marked 225%, 250% etc. The line A-B crosses the 225% curve at the point C; we draw a horizontal line through it and read on the scale, see point D, the value of 69%. This means, that a 2000 HP, 150 RPM, 60 cycle motor, with a 225% pull-out torque, of otherwise normal design, might be expected to have an average value of starting and pull-in torque up to 69% normal.

If we take the point E, where the line A-B crosses the 250% curve and draw the line EF, we will find that by increasing the pull-out torque to 250% we might expect the starting pull-in torque to go up to a maximum of 92%. Obviously these are only approximate figures, event hough they are extremely interesting.

If we take a small capacity, low speed motor like 300 HP, 100 RPM, .8 P.F., 60 cycle pole, even with a 250% pull-out torque, we will find that its starting torque is only 45% normal. Such a motor, if built, might not be capable of starting and pull-in step a mill requiring a 50% torque, even when started at full voltage.

This is a purposely selected extreme case to illustrate a diametrically opposite point, namely, that in practically all cases a synchronous motor, otherwise suitable for driving a rolling mill will ordinarily have sufficient starting torque. In the greatest majority of cases the available full-voltage starting torque is more than ample and we should think more of the starting KVA and of their effect on the power system.

As a general rule the mill motors, even though they are expected to be started at reduced voltage should be designed to withstand full voltage starting. This means that the coils should be well secured and braced—rather inexpensive insurance against any emergency which might come up.

Starting KVA. High Torque Efficiency

For a given value of starting torque the starting KVA depend on the torque efficiency, the definition of which has been already given. For such 60 cycle synchronous motors as used for steel mill drives a value of 25, 30 or 35% might be reasonably expected.

If we take the same 2000 HP, 150 RPM, 60 cycle, 48 pole motor, with a 250% pull-out torque, the average between the starting and the pull-in torques may be as high as 92%: say the starting torque is about 110% and the pull-in torque is 70%. Now, if the torque efficiency of this design is about 30% (we are assuming this value merely for illustrating purposes), then the full-voltage starting KVA will be $\frac{110}{.3} = 367\%$ normal, or over 7000 KVA.

Many attempts were made to improve the torque efficiency, i. e. to get a higher torque for the same KVA, or to get a lower KVA for the same torque. Broadly speaking, this improvement is obtainable by reducing the reactance of the machine by any means available to the designers; this is one reason why, for instance, the 25 cycle motors have higher torque efficiency than the 60 cycle machines of similar HP and speed. For instance, the 4000 HP, 83 RPM, 25 cycle motor, shown on Fig. 11, has a torque efficiency close to 50%. The designing engineers can also go a certain length in the same direction by increasing the number of slots per per pole in the stator and the number of bars in the pole pieces; also by varying the ratio of pole face to pole pitch, etc. In other words, an induction motor design is adopted for a synchronous motor.

Considerable progress has been lately made in this line. For instance, a 600 HP, 300 RPM, 2200 volt, 60 cycle motor driving a cement mill has been recently built for full voltage starting, with the idea of getting as much starting torque as possible; a 288% torque, 423% KVA, 68% torque efficiency were actually obtained on the test floor.

It should be realized, that when we reduce the machine reactance, although we improve the torque efficiency, we also increase the starting KVA. This method is therefore helpful in such cases when a very high starting torque is needed,—(more than can be obtained at full voltage starting with a normal design), regardless of the value of the starting current. This is not often the case with the main roll drives, and ordinarily, even with a 25-30% torque efficiency, good results might be obtained.

If a synchronous motor has been designed for a certain value of starting and pull-out torque, then its physical dimensions and its starting KVA are more or less determined. However, the running or rated KVA depend on whether this is a 1.0 or a 0.8 P.F. machine, being greater in the latter case. Therefore, the torque efficiency has always a higher numerical value for a 0.8 P.F. motor, although the actual starting KVA may be the same as for a 1.0 P.F. motor of otherwise similar characteristics.

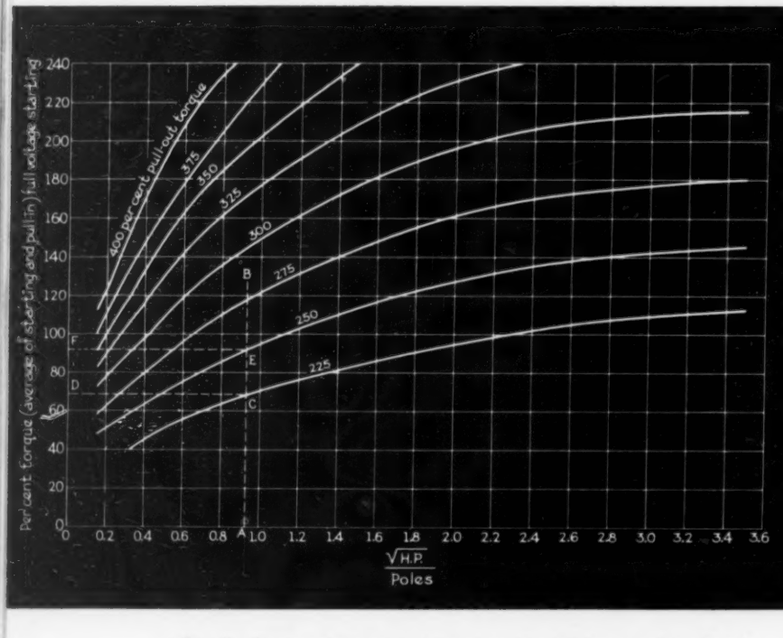


Fig. 7—Per cent Torque (average of starting and pull-in) normally availeble when starting at full voltage 0.8 power factor, 60 cycle synchronous motor.

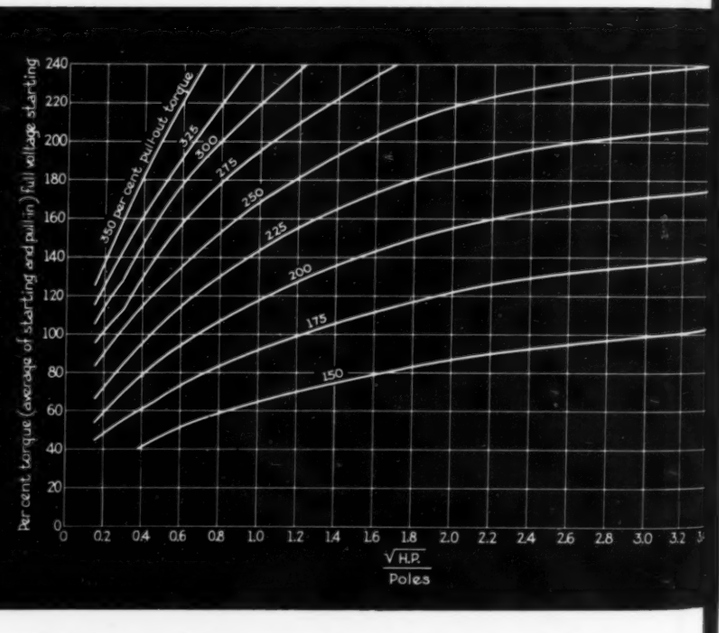


Fig. 8—Per cent Torque (average of starting and pull-in) normally available when starting at full voltage 1.0 power factor, 60 cycle synchronous motors.

SYNCHRONOUS—INDUCTION MOTORS

Before the synchronous motor fully came into its own, several attempts were made both in the U. S. A., and in Europe, to take a slip ring induction motor, to use it as such during the starting periods (with a low starting current) and then to apply D-c. excitation to the rotor; the machine then pulls-in step and behaves as a synchronous motor, with leading P.F. etc.

The scheme is quite workable in principle. But the induction motor becomes a very inferior synchronous machine. The very small air gap makes the pull-out torque quite low,—hardly suitable at all to any steel mill drive. The design of the rotor winding calls for a very low excitation voltage, say 50 V. or thereabout; special exciters are therefore needed.

One of the attractive features of the synchronous motor—simplicity of the rotor construction and absence of phase-wound secondary is sacrificed, just to take care of starting conditions.

It is believed that this hybrid design will find a very narrow application field in industry, in view of the progress made on synchronous motor design.

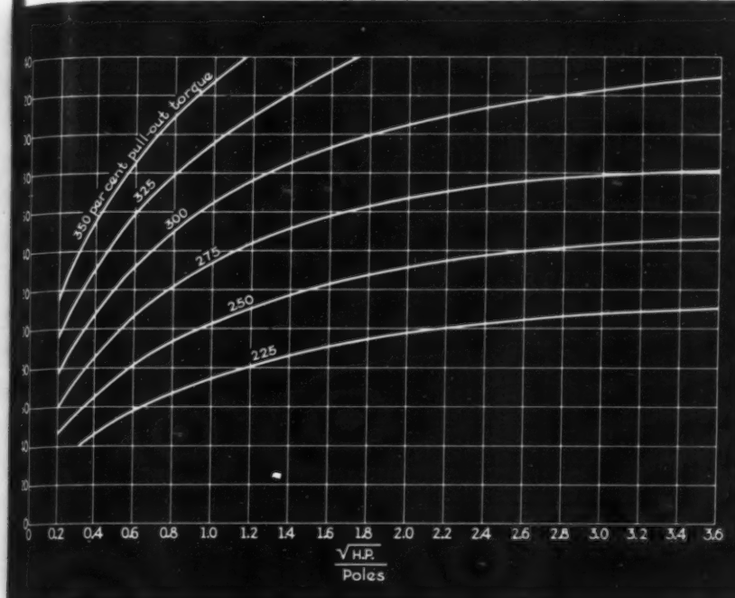


Fig. 9—Per cent Torque (average of starting and pull-in) normally available when starting at full voltage 0.8 power factor, 25 cycle synchronous motors.

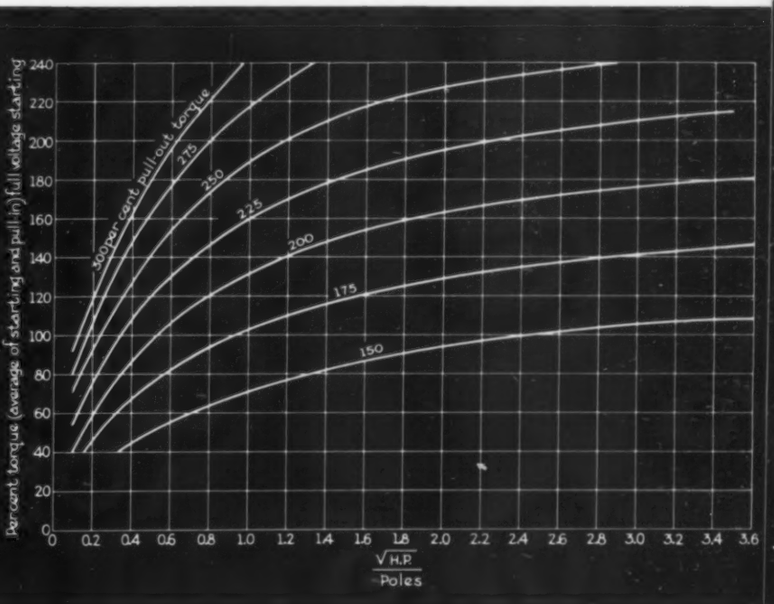


Fig. 10—Per cent Torque (average of starting and pull-in) normally available when starting at full voltage 1.0 power factor, 25 cycle synchronous motors.

PLUGGING AND DYNAMIC BRAKING

In 99 cases out of 100 means should be provided to reverse or plug the main roll drive. Opinions may vary how important it is to plug a drive without a flywheel. But all operating men will agree that it is mighty convenient to be able to back-out a mill when a cobble occurs, or during mill adjustments. Reversing control is therefore provided. It is seldom required to attain full speed and to synchronize in the reversing direction; if any simplification of control is hereby obtained, it is satisfactory to reverse the motor at reduced voltage only.

Once reversing features are provided, they might as well be used for plugging the motor, i. e. for reversing the phase rotation, while running at full speed, thereby creating a braking counter-torque bringing the mill to a quick stop. It is quite obvious, that the excitation should be removed before plugging; in fact 2-3 seconds or so should be allowed after the removal of excitation and the closing of the reverse breaker.

The synchronous motor, when plugged, acts again as a squirrel cage motor. The KVA input at plugging is about 15-20% higher than the KVA input at starting at the same voltage.

If reversing features are not required, but some sort of braking for a quick stop is needed, then a possibility of dynamic braking may be investigated. Under this arrangement, the stator winding is disconnected from the line and is connected to a braking resistor; the excitation remains applied; the motor acts as a synchronous generator and the mechanical stored energy is absorbed as heat in the resistor. This method is quite widely applied in the rubber industry, where the motors used are of much smaller capacity and lower voltage than around steel mills.

A separate dynamic braking oil switch is required, properly interlocked with the main oil circuit breaker. The former does not have to be of a high interrupting capacity, and will cost less than the line breaker; the dynamic braking resistor should be insulated for full line voltage and will undoubtedly require appreciable space for motor of any considerable size.

Under circumstances it is not expected that the

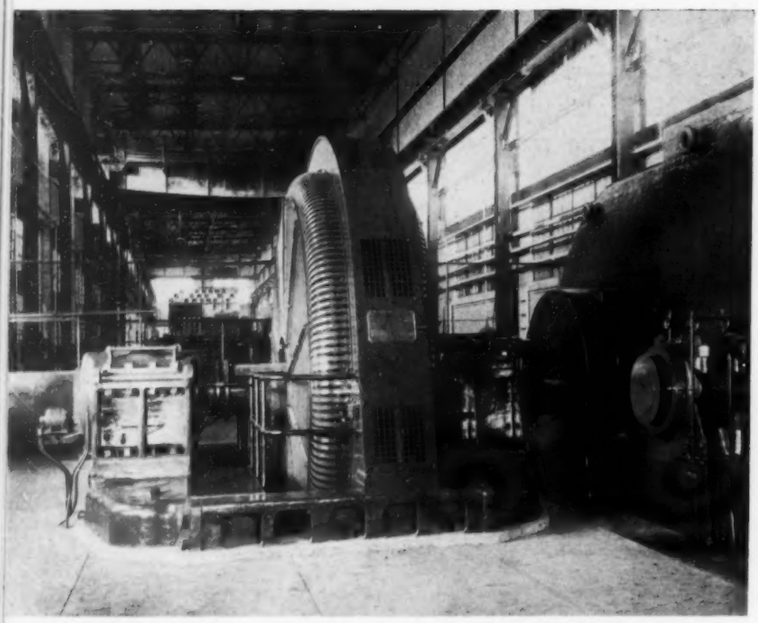


Fig. 11—Synchronous motor rated 4000 hp., 83 rpm., 6600 volt, 25 cycle, .8 power factor driving the Roughing Stands of the 27-24-21″ Continuous Skelp and Sheet Bar Mill of the Bethlehem Steel Company, Sparrows Point, Maryland.

dynamic braking method will be widely used with synchronous motors driving the main rolls.

STARTING METHODS AND SWITCHING ARRANGEMENTS

Full Voltage Starting

Full voltage starting is, of course, the simplest possible one and is to be recommended wherever possible. Motors can be, and have been, built to successfully withstand the high current inrush; a motor as large as 3000 H.P., 100 RPM, .9 P.F. (See Fig. 12) installed in one of the Cleveland steel mills is regularly started at full voltage. The current inrush is a little over 300% normal, or about 8000 KVA.

The mills themselves, i. e. their couplings, gears, etc., if built to withstand high peak load during rolling operations, seem to be quite suitable for the rapid acceleration under full voltage starting. At least, no objections were raised thus far on this ground, to the best of the writer's knowledge. This does not mean, of course, that such objections will never be raised in all instances. Thus the whole question comes to this: Can the power system withstand the high starting peaks, accompanied as they are by a very low power factor? If it can—then the answer is simple. But if the reply is negative—then the drive should be started at reduced voltage, or under conditions equivalent to reduced voltage.

Assuming that this is the case, we shall analyze the several available methods of reduced voltage starting and will illustrate by example their selection.

Auto-Transformer

This is the oldest of methods still in use, although it is being more and more superseded by newer methods. Still, it has certain merits yet and it is altogether premature to bury it completely.

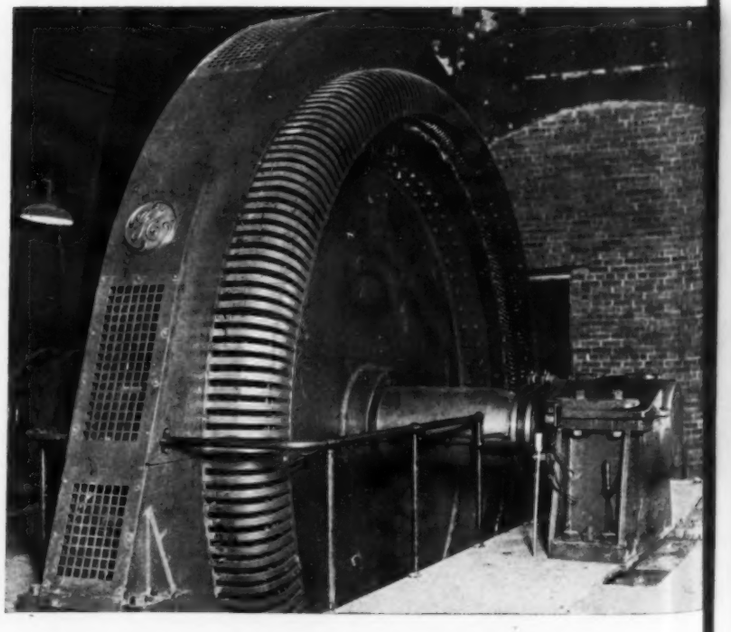
Fig. 13—represents an auto-transformer arrangement of the so-called Korndorfer type. When starting from rest, the oil circuit breakers A and F are closed, with B (and of course R) open. This applies part-voltage to the motor windings. After the motor reaches a speed sufficiently close to synchronism, the breaker A opens and B closes. The opening of A actually converts the auto-transformer into a reactive coil X connected between the motor and the line; with the proper reactance of this "reactive coil", the voltage at the motor terminals should be higher than the original tap voltage, but is of course lower than the line voltage. The closing of B short circuits the reactive coil "X" and applies full voltage to the motor.

The fact that the power is not removed from the motor at any time during starting cycle results in a minimum power disturbance as compared with any other type of auto-transformer starting.

Breaker R is used for backing-out or plugging.

Sometimes it is difficult to design the auto-transformer with just such amount of reactance X which, when in series with the motor, will give the proper voltage at the machine terminals. At some of the original large steel mill drives, a combination method was used, see Fig. 14. This is nothing but a modification of the Korndorfer scheme, except that a reactor Y, with a specially selected reactance, is used to shunt the reactive coil X,—after the breaker A opens and before B closes. This gives a properly selected inter-

Fig 12—Synchronous Motor rated 3000 hp., 100 rpm., 11,000 volt, 60 cycles, .9 power factor driving a bar mill. This motor is started at full voltage, drawing about 8000 kv-a. from the line.



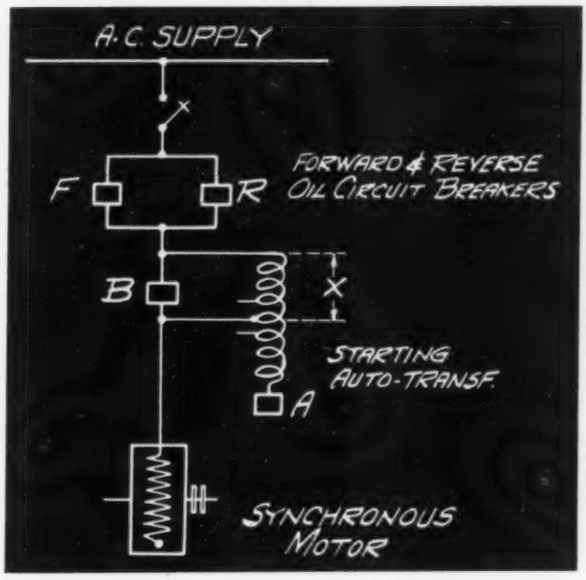


Fig. 13—Switching arrangement for the Korndorfer type of Auto-transformer starting.

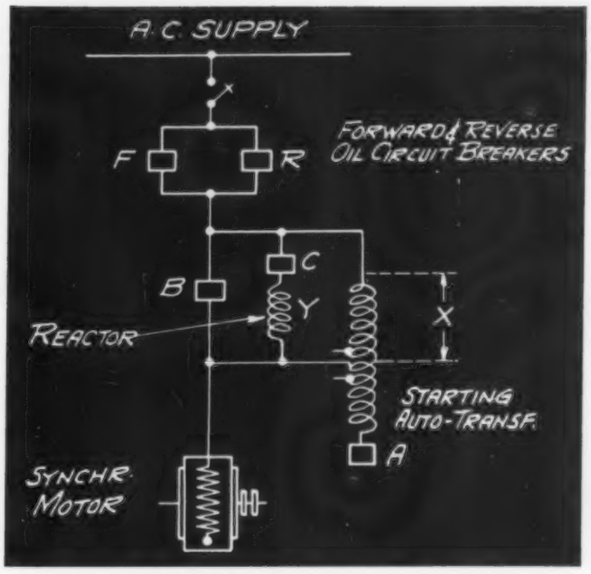


Fig. 14—Combination reactor-auto-transformer type of starting used with several large synchronous motor drives.

mediate voltage step. The initial starting voltage may be then selected as low as possible and yet the transition to full voltage will be smooth and "painless".

The reactor Y and the extra breaker C add to the total cost. They were justified in early stages of applications of large synchronous motors, when both the electrical manufacturers and the motor users were just feeling their way about this problem. It does not seem likely that this combination, transformer-reactor, method will be extensively used in the future.

Let us now illustrate an application of the auto-transformer starting by a specific example.

We assume that a 5000 HP—100 RPM—60 cycle motor is required for driving a 19", 6 Stand, continuous bar mill. An .8 P.F. (4900 KVA) motor is preferred for power factor corrective purposes. Torque requirements are given as follows: Pull-out torque—250% normal, torque to start the mill—40%, torque to pull in synchronism—30%. Due to a relatively small capacity of the power system it is desired to limit the starting KVA to not more than 9000 KVA. (considering the poor P.F. at starting of a synchronous motor).

A motor design has been laid out to meet the continuous and the overload capacity. This machine is capable of developing, at full voltage, a starting torque of 120% normal, with a starting KVA of 400% (i. e. 19600 KVA); the torque efficiency is therefore $\frac{120}{400} = 30\%$; the pull-in torque at full voltage is 80% normal. (See Fig. 15.)

Now, this motor has an inherent starting torque much higher than we need in this case. Likewise a starting load of almost 20,000 KVA is a none too pleasant aspect. Thus, some sort of reduced voltage starting is required and we apply the auto-transformer method as per Fig. 13. What should be the selected starting voltage tap?

Remember, that during the starting period, the synchronous machine behaves as an induction motor, i. e. the torque varies as a square of applied voltage. If we want to cut down the starting torque value from 120% to 40%, i. e. in a ratio of 3:1, then the voltage should be reduced in a ratio of $\sqrt{3}$:1, or 1.73:1. (If this is a 6600 volt motor, then the starting voltage will be 6600 : 1.73 = 3460 volt.) In other words, we have selected a $\frac{100}{173} = 58\%$ starting tap; the transformer ratio K = .58.

What happened to the line input? As far as the motor winding is concerned, its current input at starting is directly proportional to the applied voltage. Therefore in this case the starting stator *current* will be only 58% of 400%, i. e. only 232% of normal. But the line current is less than 232%, because a transformer ratio of K = .58 is interposed between the motor and the line; therefore the line current or line KVA will be only .58 x 232 = 135% of normal. This is only 30% of the starting KVA at full voltage, or about 6600 KVA.

Thus, by using a starting auto-transformer, we have reduced the starting torque and the line starting current in the same proportion, namely in propotion to the square of applied voltage. The ratio of the starting torque to the starting current or KVA, i. e. *the torque efficiency, remains the same*, as it was at full-voltage starting.

On the 58% tap the pull-in torque will be about $80 \times .58^2 = 26.7\%$ normal; we stated that 30% is required. It is advisable therefore to use a slightly higher auto-transformer tap, say 65%; the available pull-in torque will then be $80 \times .65^2 = 33.3\%$; in other words, the motor is likely to pull-in step at reduced voltage; i. e. with minimum line disturbance. The starting current has been slightly increased (due to a

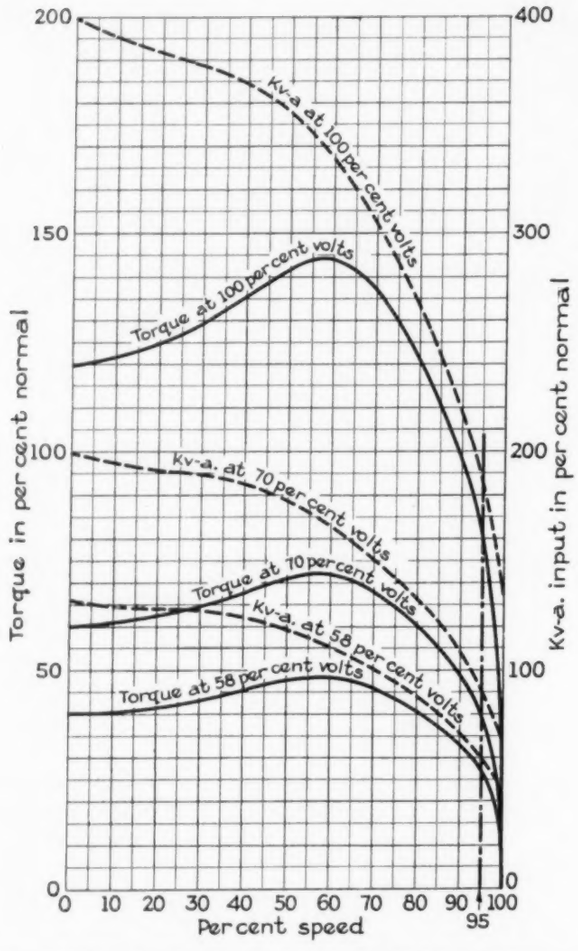


Fig. 15—Starting torques and kv-a of a 5000 hp., 100 rpm., 60 cycle synchronous motor proposed for driving a continuous bar mill. (See text for selection of starting method applied).

higher voltage tap) and is now about 168% normal, i. e. 7800 KVA, which value is still well within the 9000 KVA limit.

The auto-transformer has done what was expected of it in this case quite successfully. But we will also check whether others, may be simpler methods, will give us good results, too.

Starting Reactor Method

The general arrangement is shown on Fig. 16, (a) and (b). Electrically, both arrangements are identical; at start the reactor and the stator winding are connected in series. The total line voltage is subdivided between them; the larger are the "reactive ohms" of the reactor, the less voltage will be applied to the motor terminals.

As the motor accelerates, the current drops down, and therefore the voltage at motor gradually rises. Finally the reactor is short circuited by the breaker A; full voltage is then applied to motor. The circuit is not interrupted during the entire starting cycle. The line disturbance is thereby kept at a minimum.

Let us now try to apply a starting reactor. In order to obtain the same starting torque of 40%, we still need to apply 58% voltage to the motor terminals; the remaining 100-52 = 42% will be absorbed in the starting reactor. How shall we specify this reactor?

This motor, if started at full voltage, draws 400% line current. This means that the motor reactance is "25%", on the basis of its normal rating. Now if this motor is connected across the line with the starting reactor in series, and the latter has a "x%" reactance, then the same current will flow through both of them, and the total line voltage will be divided between the motor and the reactor in proportion to their reactances. In other words

$$25:\ x = 58:\ 42$$

Hence x = 18.1% (on 4900 KVA basis).

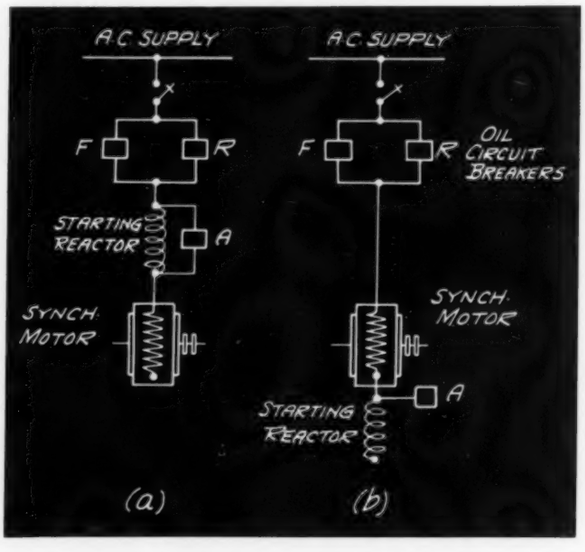
If a (25 + 18.1) = 43.1% reactance is connected across the line then the current flowing through the motor and reactor will be $\frac{100}{43.1}$ = 2.3 times (or 230%) normal.

As there is no transformer interposed in this case between the motor and the line, the line current and the motor current are synonomous. A 230% starting peak (4900 x 2.3 = 11200 KVA) is higher than the limit of 9000 KVA previously set. Thus the reactor method is not applicable on account of the relatively small power system. Auto-transformer will still be used.

Here is another example. A rod mill requires a 4500 HP (40°C)—514 RPM—60 cycle—6600 V. drive. The power system is quite large; any reasonable starting peak load up to say 10–12,000 KVA is acceptable. The power factor of the system is already close to unity, may even be slightly leading; thus a 1.0 P.F. synchronous motor is called for.

A rod mill is not subject to heavy overloads; in fact its load is as steady as might be expected on any rolling mill. The voltage at the bus is assumed to be maintained in this case very closely. The motor capacity

Fig. 16—Switching arrangements used with the Reactor type of starting.



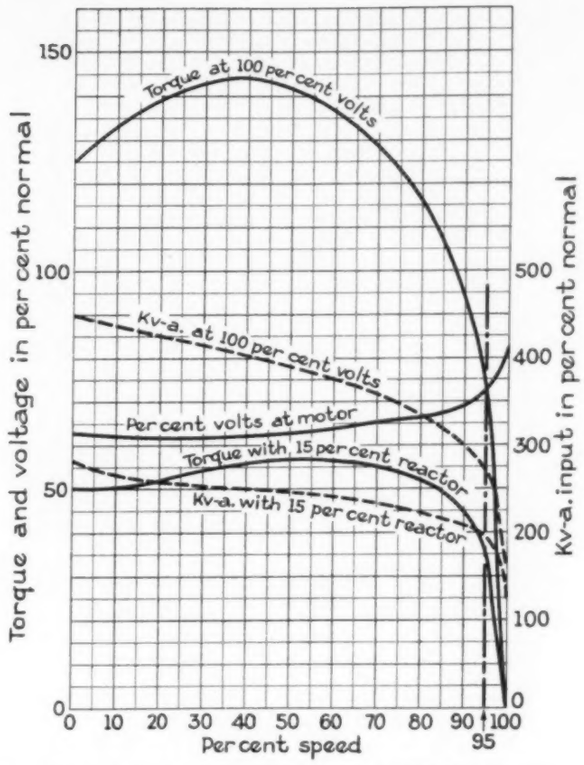


Fig. 17—Starting torques and kv-a. of a 4500 hp., 514 rpm., 6600 volt, 60 cycle, 1.0 power factor synchronous motor driving a rod mill. (See text for selection of starting method applied.)

is somehwat oversized. Thus it is felt that a 200% pull-out torque is sufficient,—which is quite a help for a 1.0 P.F. motor.

A starting torque of 50%, and a pull-in torque of 40% should be considered ample for such mill under normal conditions. However, if the mill has been shut down for a great length of time, with *all* rolls tightened down in order to maintain the gage, then a starting torque up to 100% might be needed. If it were permissible to loosen up somewhat the roughing rolls, without disturbing the finishing rolls, then the 50% torque would be found sufficient, even after an extended shut-down. Thus in this case it is decided to provide a starting torque of about 50% for all everyday occurrences, but make certain that 100-125% starting torque might be developed by the motor at full voltage, in an emergency case.

A similar motor has been designed. It has the following starting characteristics (see also, curves on Fig. 17):

Applied Voltage	% Speed	% Torque	% KVA	KVA
100%	0	125	450	15,750
100%	95	75	275	9,650
63% (reactor)	0	50	285	10,000
63%	95	40	200	7,000

Thus by starting the motor through a reactor (63% voltage applied), we will get the needed starting and pull-in torques (50% and 40%) and will limit the load on the line to 10000 KVA. At the same time, we can go, if needed, to full voltage, obtain a 125% torque but be then contended with a 15,750 KVA peak load.

We note that the torque efficiency in this case is not particularly high—only 27.8% at full voltage, and 17.5% at 63% volts. Is it to our advantage to increase the torque efficiency of this machine?

Suppose this has been done by reducing the motor reactance etc.; the torque might be increased to 250% but the line KVA are apt to go to 650% normal; thus, although the torque efficiency is now 37.5%, but the line KVA, if started at full voltage, would be 22,600 KVA, which is not at all attractive.

The performance of the high-torque-efficiency motor is not particularly advantageous in this case also when starting on reactor. To cut down the motor torque from 250% to 50%, a voltage of 45% normal would be required; this would call for a reactor of 18.7%; together with the motor reactance of 15.3% it would limit the starting KVA to $\frac{100}{18.7 + 15.3} = \frac{100}{34} = 2.93$ times (293%) normal.

Although the motor itself has a high torque efficiency, the starting KVA are actually higher (293% vs. 285%), as compared with the original design, for the same torque developed. This example shows that it would be a misapplication to use a high-torque-efficiency motor with a reactor. This design should be used either for full voltage starting, or with an auto-transformer, which maintains the torque efficiency, or with a still another method (part winding) to be presently described.

Referring again to Fig. 16, we should compare the arrangements (a) and (b). With the first arrangement the reactor is located between the line and the motor; under (b)—the reactor and its short-circuiting breaker A are connected in the Y-point of the stator winding. Advantages:

1—Reactor and breaker A are protected by the motor reactance against short circuits on the line.

2—For this reason the reactor and the breaker may be designed to withstand a smaller short circuit current.

A disadvantage of this method is that six leads must be brought out of the machine and—if all high voltage apparatus is to be located together—an extra cable should be laid between the motor and the switching structure. The latter objection is often met by locating the reactor and its breaker at the motor, say in a compartment at the foundation.

Part Winding Starting

It is always advisable to keep in mind the lately developed method of part-winding starting. It is the natural outgrowth of the fundamental principle of a double winding synchronous generator, originally applied to very large capacity turbo-generators with the idea of limiting the amount of KVA connected to one bus section.

Similarly, the synchronous motor may be provided with 2 parallel windings, each of half capacity, and

suitably laid in the stator slots. When both windings are energized the motor behaves as if it were an ordinary single-winding machine. Now, suppose that the power is applied to only one of the two windings at starting. This will have the effect, in an ideal case, of cutting down to half value both the torque and KVA, as compared with starting on both windings. The torque efficiency is maintained, or very nearly so.

To accomplish such favorable results, it is necessary to properly space the stator coils; this is most convenient when the number of poles is a multiple of 4 (i. e. 16, 20 etc.). When this best coil spacing is not feasible then the torque efficiency might suffer somewhat; in the extreme case, when the two windings are laid in alternate slots, the starting conditions may be equivalent to a reactor starting of a conventional motor at about 70% voltage; the torque will be cut down to approximately 50% and the KVA to approximately 70% of full voltage, full winding values.

The advantages of the part winding starting are obvious—absence of any device such as an auto-transformer or a reactor, and a switching as simple as that used with a reactor. Suppose the line ends of both windings are connected together and are controlled by one line oil circuit breaker; the neutral of one winding is permanently closed, the neutral of the other is open during the starting and is closed by an oil switch after the starting has been completed. Thus only one extra non-automatic switch is required as compared with full voltage starting. The shortcoming of this method is that the lack of flexibility in adjusting the starting torque; there are no reactors, nor auto-transformers and therefore no taps to change the starting voltage, if necessary. There is no reason why the number of parallel motor windings should be limited to two; 3 or 4 windings are also feasible, to give in effect 3 or 4 starting steps. But this of course would require more switches.

Now let us try out to apply the part winding starting method to the same 5000 HP—100 RPM motor already used in previous illustrations. We will assume that the two windings are well placed, so that the torque efficiency is maintained. We should then obtain a 60% starting torque and 200% starting KVA. The torque is 1.5 times the required value (40%) and this is not objectionable of course. The starting load is however 9800 KVA which is slightly more than the 9000 KVA limit. But the excess is less than 10%, and the temptation of getting rid of the auto-transformer and two extra breakers is admittedly great. If at all possible, we should have tried in this case to work-in the part-winding method.

Y-Delta Starting

If the machine is delta connected, then it is possible to obtain the effect of reduced voltage starting by connecting the windings Y during the starting period. The voltage per phase is then reduced as $\sqrt{3} = 1.73 : 1$. The effect on torque and line KVA is exactly the same as if an auto-transformer with a 58% voltage tap were used: the torque and KVA will be 33.5% of full voltage values; the torque efficiency will be maintained.

Theoretically at least, this method has merits as auto-transformers and reactors are eliminated. But it also has serious shortcomings. In the first place the method is inflexible; 33% of full voltage torque might not be sufficient; the gap between 33% and full torque is too large and there are no intermediate steps.

Secondly, it requires a delta connected motor. For high voltage machines, like 6600 V., or 11,000 V., it is more convenient to Y-connect the stator for normal operation.

Thirdly, when changing from Y to delta, the motor circuit is opened and then closed again. This is always undesirable because it is apt to cause more voltage disturbance during the transition period.

Finally, it requires a more elaborate switching than either the reactor or the part-winding methods.

Under circumstances, it is not reasonable to expect a wide use of the Y-delta method of starting.

Starting Bus Arrangement

When many synchronous motors or motor-generator sets are located in the same motor room, and a reduced voltage starting is required, an idea of a starting bus gives, often times, very good results and saves first cost as compared with individual reactors or auto-transformers. No starting bus is involved, of course, if part-winding method is applied to every machine; this is a strictly "individualistic" method.

Fig. 19 shows a reactor starting bus arrangement. The starting bus is energized through the starting reactor, protected by the breaker M. Each motor is equipped with a running breaker F, starting breaker S and (if this is a main drive motor) with a plugging breaker R. Not more than one of the several breakers S and R can be connected simultaneously to the starting bus (this is provided for by suitable interlocking).

To start any motor, its breaker S closes, then, at proper time, its breaker F closes, tripping S and making the starting bus available for the next motor, if needed.

Breakers F and M—are of the interrupting capacity determined by short circuit study of the system; breakers S and R—are non-automatic and naturally are of much smaller size and cost. The grouping of breakers and buses readily lends itself to metal-clad or truck-type structures.

The question of selecting the proper reactor with this arrangement presents a certain interest, particularly when the capacity of the several motors covers a wide range. This matter may be best explained by means of an example.

Suppose the following machines were installed in the same motor room and have characteristics are indicated in lines 1 to 4 of the tabulation.

1. Motor Rating in KVA	5600	1400	2000	3000
2. Application	M-G Sets		Mill Drives	
3. Motor reactance in % of its rating	20	22	30	25
4. Minimum voltage required for starting	35	35	60	50
5. Reactance of the reactor, in %, on 5600 KVA basis	37	....	....	....
6. Reactance of the reactor, in %, on basis of KVA of each machine	37	9.25	13.2	19.8
7. Total reactance in circuit when starting	57	31.25	43.2	44.8
8. Starting KVA, in %	175	320	230	223
9. Starting KVA	9750	4500	4600	6690
10. Voltage at motor, in % normal	35	70	70	56

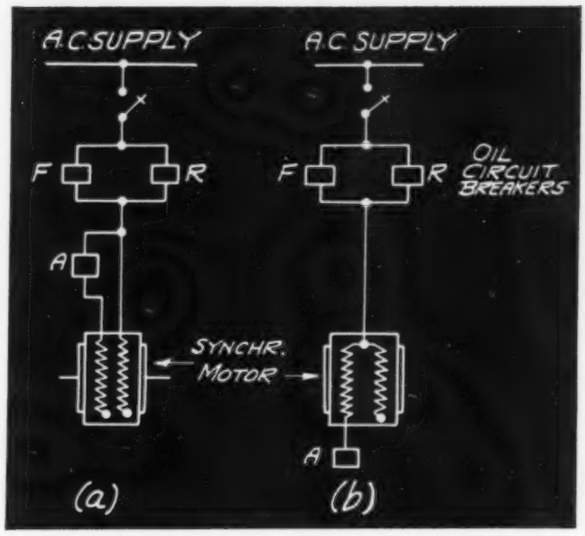
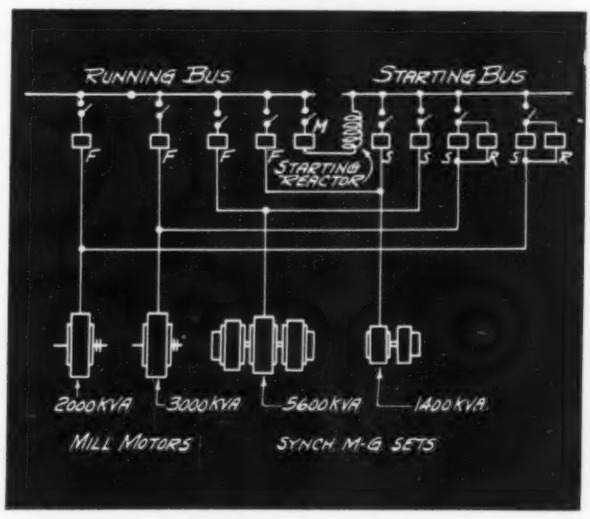


Fig. 18—Switching arrangements used with Part-winding type of starting.

The reactor was selected to limit starting KVA to a value strictly necessary when starting the larger machine, the 5600 KVA synchronous motor of the 4000 KW MG set. It requires, let us say, 35% voltage to start; its reactance is, say, 20% (on 5600 KVA basis). A 37% reactor is selected; then (see tabulation) the starting peak is 9750 KVA. A further study will show that the smaller (1000 KW) M-G Set, if started on this reactor will receive 70% voltage at start and will pull 320% KVA. This percentage sounds high if we think in terms of machine rating; but if the reactor is used primarily to protect the power system from excessive starting peaks, then of course a 4500 KVA peak when starting the 1000 KW set cannot be objected to, if a 9750 KVA peak is acceptable. The 2000 HP and 3000 HP mill drives require 60% and 50% starting voltage; the selected reactor gives then 70% and 56% respectively; thus everything seems to be in order. But if, for instance, the 3000 HP motor needed 60% starting voltage, then it would be necessary to reduce somewhat the reactor's reactance and to be satisfied with slightly higher starting peaks.

A number of large steel mill installations are arranged in this manner and operate quite successfully, as should be expected.

Fig. 19—Starting Reactor bus arrangement.



Choice of Control Scheme

The chief requisite of any type of starting equipment is simplicity. From this standpoint the various schemes may be put on the list, in order of their desirability:

1. Full voltage starting
2. Part-winding starting
3. Reactor starting
4. Auto-transformer starting

It is suggested that the application engineer, in making the choice, always starts from the top of list and goes only as far down as necessary to meet the local conditions.

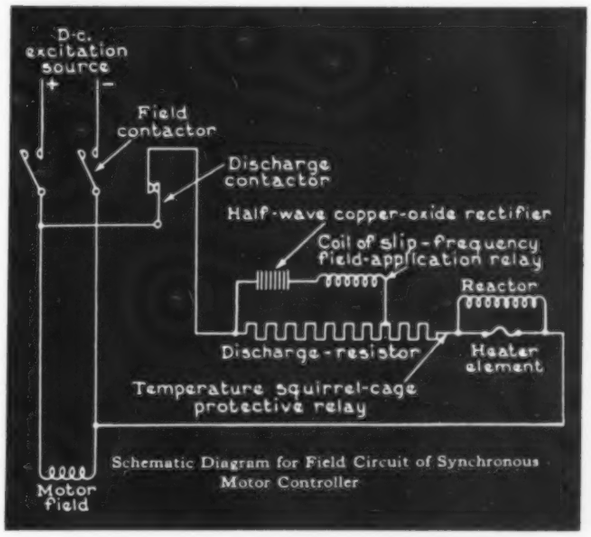


Fig. 20—Schematic diagram for Field circuit control of synchronous motor. (G. E. arrangement).

DUTY CYCLE OF STARTING APPARATUS

The starting apparatus, such as the auto-transformer or the reactor, as well as the squirrel cage winding of the synchronous motor may be called upon to operate rather frequently. It is hard to generalize how often would a mill start in a course of a day. Sometimes it will run several hours at a stretch; on other occasions (when the cobbles are abundent:) it will be started and stopped several times in an hour. During the mill adjustments the drive is apt to be jogged several times in succession; while each jogging does not heat up the squirrel cage winding, nor the reactor, as much as each complete start does—a large amount of jogging will greatly contribute to the heating.

Now it is impossible to evaluate by any statistical method the number and the relative effect of these

operations on the starting apparatus. It is therefore suggested that an arbitrary duty cycle be specified and the starting apparatus, if built to meet this duty cycle, should be amply large for actual working conditions. As an equivalent duty cycle of this kind, the following specifications may be suggested:

The starting reactor (or auto-transformer), should be suitable for not less than 5 consecutive starts, each of which lasts 1 minute, with 1 minute intervals. After a 2-hour rest period, another 5—one-minute starts will be made, with 1-minute intervals. After this the starting devices will be allowed to cool off. The starting load during each starting period is assumed to correspond to the initial current inrush (blocked rotor value). The field discharge resistor and the squirrel cage winding of the synchronous motor should be good for duty cycle at least as severe as given above.

It is, admittedly, very difficult to prove on a theoretical basis the correctness of this specification. The starting periods last usually less than 1 minute (ordinarily not longer than 30 seconds). The RMS current is usually less than the initial current; but, on the other hand, a larger number of consecutive starts than 5 might also occur. The best argument that can be advanced in favor of this specification is that several dozens of equipments, built substantially in accordance with it, have been found to be of ample capacity in actual practice. The writer would be rather reluctant to make these requirements less rigid unless a definite proof is presented that this would be satisfactory.

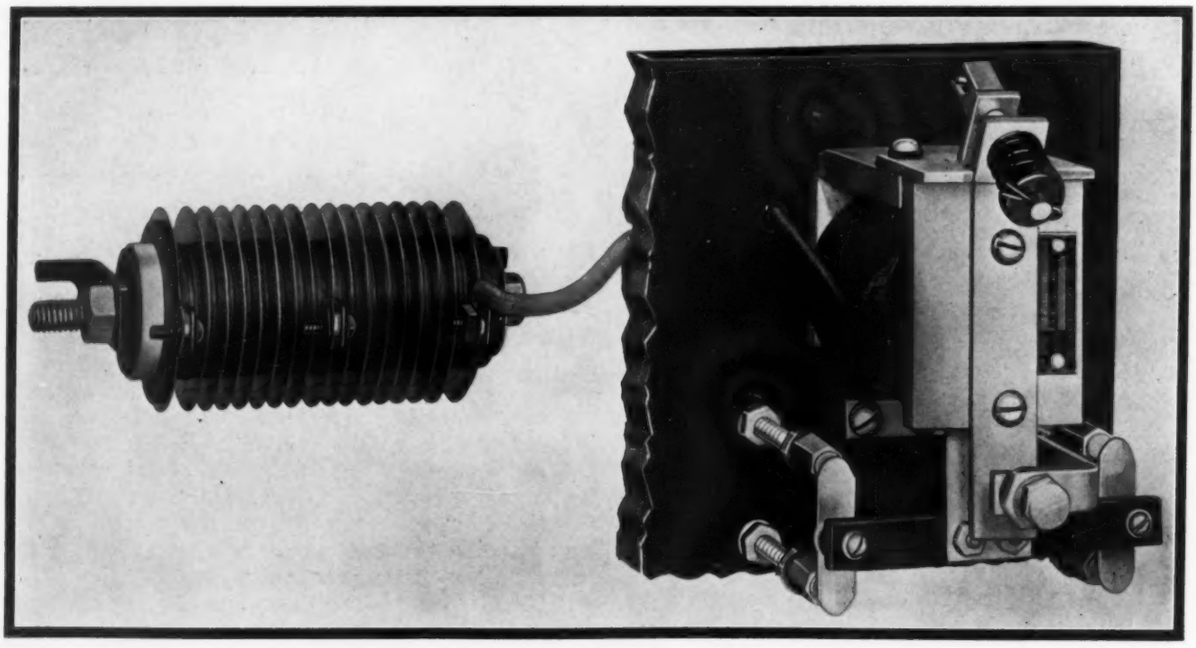
LIMITATIONS OF SYNCHRONOUS MOTORS

Anything which is new and has been successfully applied in many instances, is apt to be pushed beyond its proper and legitimate field; in other words, it is apt to be misapplied. Synchronous motors may also fall victims to such over-enthusiasm on the part of its supporters.

The first possible pitfall is to consider the synchronous motor only in connection with the drive itself, rather than with the whole power system. The latter may be large enough to withstand any reasonable starting or running peak load which might be expected of a synchronous motor drive; but the over-abundance of synchronous capacity on the system may cause us to prefer a squirrel cage induction motor, which also is a very simple and reliable machine. This is exactly what happened in one large Mid-Western Steel Plant.

Then, we still have to deal with such mills, which are better off if equipped with flywheels, as otherwise the repeated load peaks might be as high as 300-400% of the required normal rating. To be sure, even then an oversize synchronous motor can be built and applied instead of a more logical choice of an induction motor; but it might be difficult to justify this application on engineering grounds. After all, the advent of the synchronous motor does not necessarily make all other types of motors automatically obsolete. The induction motor is far from dead—and the electrical engineers should be glad to have now two tools to work with, instead of one,—when constant speed drives are concerned.

Fig. 21—Slip-frequency Field-application Relay for synchronous motors. For connections—see Fig. 20.



SYNCHRONOUS M-G SETS FOR MAIN ROLL DRIVES

The use of synchronous M-G sets for furnishing power to D.C. motors driving the main rails, is very much older than the application of synchronous motors to the drives themselves.

The starting problem is easily solved, as in practically all cases the sets are started without load. The machines involved are high speed, with rather low reactance, and the full voltage starting current is apt to be 5-7 times normal. Therefore full voltage starting is seldom applicable for M-G sets of any appreciable size. Part-winding, reactors and auto-transformers are used, the choice of the method being done on the same basis, as previously discussed.

The pull-out torque should correspond to the overload requirements of the mill motor. If the M-G set feeds only one drive then this relationship between the overload capacities is obvious. If, however, one set supplies power to several motors, then it is not very probable that all of these motors will be subjected to the maximum momentary peak loads at the same instant. Practice shows, that a pull-out torque of 200% normal rating, is ordinarily ample for the synchronous M-G set, provided its continuous capacity is well selected to suit the RMS load. This applies to such mills as merchant, strip, bar, etc.

Synchronous motor-generators for supplying power to reversing mills are in a class by themselves. The writer is particularly partial to this application, having advocated it since 1926. Two reversing bar mills in Pittsburgh district were the first ones to be equipped in this fashion; the capacity of the reversing motors were 2150 Hp and 3000 Hp respectively. Then, in 1929, a 90-inch reversing plate mill drive (4000 HP) was equipped with a M-G set provided with a 5000 HP synchronous motor having a 15,000 HP pull-out torque. The finishing stand of a wide flange beams installed in Chicago district in 1930 is driven by a 6000 HP reversing motor and the latter is also supplied with power from a synchronous M-G set. Few recent 3-high mills (plate and rail) with adjustable speed D.C. motor drives (control similar to the reversing mill control), conventionally equipped heretofore with flywheel sets, were provided with synchronous motor generator. Thus this application is growing in popularity. Although it is difficult to foretell now when a full size blooming mill will be similarly equipped,—the writer has no doubts that this day will also come.

Now the pull-out torque of such M-G sets should be very carefully considered, because the peak loads of reversing mills themselves as high as 300% normal are not unfrequent. The synchronous motor of the set should also stand that load. Means to obtain high pull-out valves though over excitation were already discussed.

PROTECTIVE FEATURES FOR SYNCHRONOUS MOTOR DRIVES

Protective Features for Synchronous Motor Drives—

While the control for synchronous motors is not intended to be covered by this paper, the salient protective features to look for in such a control should be outlined.

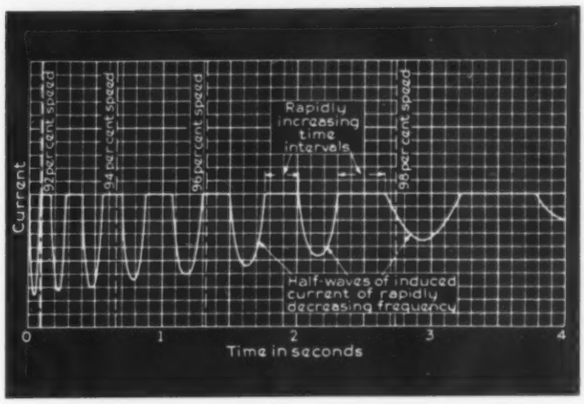


Fig. 22—Current in the coil of the slip-frequency field-application relay near synchronous speed. For connections—see Fig. 20.

The synchronous motor, driving a rolling mill, should be protected against:

1. Phase-to-phase and phase-to-ground short circuits in the stator winding.
2. Overheating of stator winding.
3. Overheating of squirrel cage winding, in case of excessively heavy and repeated starting duty or running without excitation.
4. Loss of excitation.

The protection against phase-to-phase and phase-to--ground short circuits is not different from similar protection given to any large a-c. machine connected to a high-voltage system. Differential relays; phase-balance relays; ground relays and others should be considered and the selection made on the basis of the characteristics of the machine and of the power system; the decision is obviously influenced by the fact whether the system is grounded or not.

When the starting peaks are very high—as in the case with full-voltage starting equipments, for instance, —the conventional induction type overload relays should be set so high, that a separate overheating protection should be provided for. A good temperature relay, with heating characteristics to match those of the motor is a good investment, if the overheating of the motor is to be guarded against. If the machine is equipped with temperature detector coils,—as large machines usually are—then these coils could be also used directly to either indicate the motor temperature, or to sound an alarm, or if so desired—to trip the breaker.

The duty of the squirrel cage winding, when the motor is running at synchronism, is very light as compared with its capacity, and it will not overheat. Its real duty covers the starting periods and also the time after the machine is pulled out of step, but the power is not cut off. If the starting winding is to be protected against overheating, then an arrangement similar to one shown on Fig. 20, may be foreseen. The idea of this arrangement is this: A temperature relay is connected in the field discharge circuit, in multiple with a

reactor; as this circuit is really connected magnetically in parallel to the squirrel cage winding, the current flowing through the field discharge resistor bears a definite relationship to the squirrel cage current. The greater is the slip, the greater portion of the field discharge resistor current flows through the heater element, as the reactor's reactance grows rapidly with the slip. Thus the relay is very sensitive and "knows" well when the starting (squirrel cage) winding is apt to overheat.

The protection against the loss of excitation may be arranged on two different principles. We may desire to trip the motor whenever the excitation fails, not wishing to take any chances of running the motor as a squirrel cage machine. A field current relay is then provided, which is arranged to trip the breaker if the field current fails. The greatest majority of main roll drives is arranged in this manner, which is, of course, the safest way; the cases of excitation failures are few and far between, so that the rolling operations will not be frequently interrupted on this account.

If the second principle is followed, no "excitation failure" relay is provided at all. If the excitation fails, the motor is allowed to run as a squirrel cage machine, merely waiting for the return of excitation voltage, when the motor will be automatically re-synchronized. In the meantime the most vulnerable part of the motor (its squirrel cage winding) will be protected by its temperature relay, *if such is provided*. Therefore, the motor will run, waiting for the excitation to return, only so long as it is considered safe for it.

To explain better the required performance of the motor control, it is advisable to briefly mention how and when the field excitation is applied to the synchronous motor and how it is automatically removed when the motor pulls out of step. The diagram, Fig. 20, and the accompanying photographs, Fig. 21, illustrates the arrangement, developed by the Company with which the writer is associated.

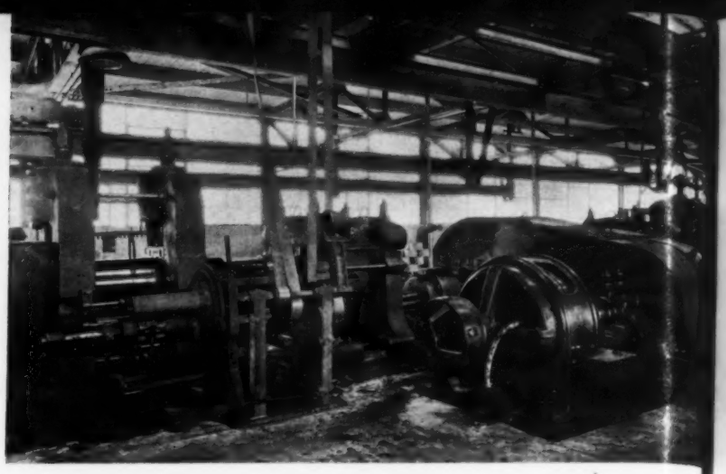
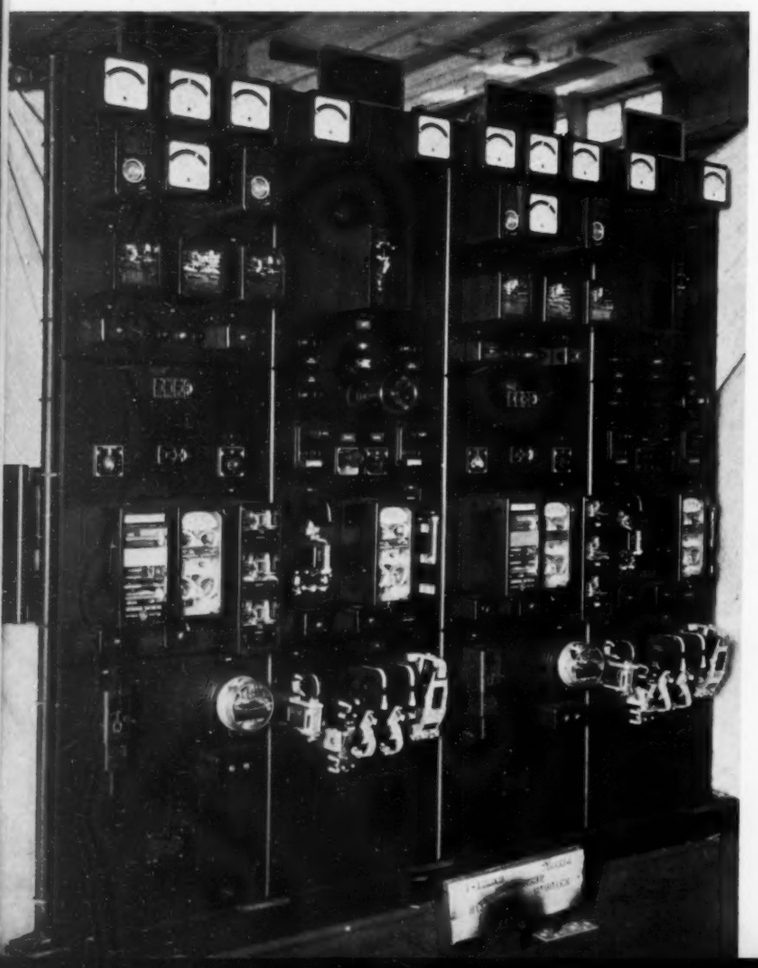


Fig. 24—400 hp., 720 rpm., 4600 volt synchronous motor driving an 18-inch brass mill.

A Slip-Frequency field application relay, with a half-way copper oxide rectifier in series with its coil, is connected across a portion of field discharge resistor. The relay itself is of well known D.C. magnetic time type, thousands of which are used on steel mill auxiliary panels. At low motor speeds, the frequency applied to the relay coil is relatively high, the intervals when the rectifier does not let any current flow through the coil are very short,—and therefore the relay is held closed. When synchronism is approached, the slip-frequency gets low, and when the time intervals get just greater than the time lag of the relay, the latter closes and field is applied. Fig. 16 explains the performance of this relay. A very accurate setting of this relay is possible because the time-intervals grow very rapidly when synchronous speed is being approached.

Assume now that the motor is pulled out of step. It is practically impossible to re-synchronize the motor without first removing the excitation. The sooner this is done, the better. A power-factor field-removal relay, may be provided to do this trick. The principle of operation is quite simple. No synchronous motor, when running in synchronism, runs with low lagging power factor. Even if we take a machine with 1.0 p.f. at rated load, and impose a heavy overload, the power factor will never go below .7 lagging. However, if the motor is pulled out of step, the power-factor drops to a very low lagging value. The field-removal relay, which responds to the power factor of the stator circuit, operates at about 60% p.f., see Fig. 19, and removes the field. The motor can then run as a squirrel cage machine until the load peak passes, after which the motor can resynchronize automatically, or until the squirrel cage temperature protective relay shuts the motor down.

Fig. 23—Shop view of Automatic Switchgear Panels for two 5000 hp., 10,000 volts, 50 cycle synchronous motors driving continuous bar mills.



CONCLUSION

The synchronous motor has created for itself a deserved position in the rolling mill industry. It needs no introduction now, when about one-eighth of the total h.p. capacity of main roll drives consists of synchronous motors (not counting at all the synchronous M-G sets). The near future might see a still more general use of this type of drive.

We should only hope that this progress will not be marred by misapplication of synchronous motors to such drives for which they are not so well suited. The legitimate field of synchronous motors is broad enough by itself.

THE CONTROL AND RECORDING OF ROLLING MILL PRESSURES

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Paper presented before the A. I. & S. E. E. Spring Engineering Conference, Youngstown, Ohio, April 22, 23, 1936

▲ ONE OF THE most important factors in the development of the rolling process has been an appreciation of the variables affecting the magnitude of the rolling pressure. In early mill designs, where only two rolls were used, it was soon recognized that as the material became wider, and larger diameter rolls were required for maintenance of gauge uniformity, a point was soon reached where no increased reduction could be effectively taken. A study of the rolling pressures showed that larger rolls required greater pressures for a given reduction than the smaller rolls, and thus the efficacy of the 4-high mill became established. The essence of this design, of course, is that the use of the smaller diameter work rolls results in lower rolling pressures, large diameter backing-up rolls being employed to preserve gauge uniformity. The impact of this design on the rolling mill industry is ever increasing.

What may be said for cold rolling, of course, is also true for hot rolling, but the former involves the factors to a more important degree. Thus, as the requirements for wide strip became crystallized, the problem of bearings with sufficient capacity arose. And as the desirability for lighter gauges in wide strips developed, certain difficulties in rolling technique became significant. These problems have arisen owing to the unavoidable flexibility of the most rigid rolling mill structures. It must be appreciated that when rolling steel involving millions of pounds, the composite internal flexibility of the mill parts may easily exceed the gauge of the strip being rolled. This is contributed to by the elongation and bending of the housing posts; deflection of the screw threads in the main screws and boxes proper; bending of the roll assemblies; contact flattening of the rolls, etc.

Thus it becomes obvious that in rolling light gauges, the work rolls must necessarily be in contact before the strip is entered; the amount of initial pressure being a function of the composite mill rigidity, the strip gauge being rolled, and the reduction. Many early disastrous experiences were had, however, when operators, wishing to increase their reductions, operated their screwdowns to bring their rolls tighter together. The increase in reduction was so small in proportion to the screw travel that excess pressures were developed before realized, with resultant costly roll breakage. Apparently what happens is that the roll contact stresses become so high that the corresponding roll flattening offsets, as concerns the possibility of additional reduction, the effect of the higher roll pressures.

M. STONE

Of course, in the normal rolling of steel, the inevitable deflection of the rolls must be compensated for by proper roll crowning to obtain flat strip. Thus, for a given set of rolls, with its corresponding crown, there is only one proper rolling pressure at which uniform gauge material is obtained—all other variables being held constant. This factor is particularly important in skin pass rolling, and is beginning to be properly recognized.

Thus we see at least three important reasons in the cold rolling of steel why mill loads should be a constant concern of the operator: Avoidance of bearing overloads and breakage or premature fatigue (of roller bearings); prevention, in the thin gauges, particularly,

of excessive rolling pressures resulting in roll spalling and fracture; and the maintenance of a desirable constant load for accuracy in flat rolling. Then, too, as a means of obtaining the necessary rolling information on new materials, such as the stainless steels, etc., equipment of this sort is essential.

In hot mills, other factors assume a certain importance as well. For the continuous hot mill, with the stands arranged in tandem as they usually are, the proper and economical operation of the mill involves loading each stand with its appropriate share of the burden. This is, naturally, equally as true for tandem cold mills—thus avoiding, as has happened in many mills, the underloading of some mills at the expense of the others. Another important factor, significant to hot and cold rolling alike, is the proper setting of both screws. No better method is available for setting the mill than to have both screw loads alike—in this manner, any material of variable gauge from side to side can easily be compensated for. In hot rolling, if the roll cooling sprays were to clog on one side of one or more mills, the resultant product would vary in gauge from side to side—and undoubtedly interfere with the proper hot coiling at the high speeds in common use.

A scrutiny of the various possibilities in devising instruments for the continuous indication of rolling loads leads to a division into two general classes: The interposition of a calibrated instrument at some position in the loaded mill, preferably between the load screws and the bearing chocks; and the utilization of the strain of various parts of the mill structure proper to actuate attached instruments. In the past, the first class has received the greater attention—the first work of this kind having been carried out by Puppe in Germany, using hydraulic jacks placed between the screw points and the bearing chocks. However satisfactory this may be for laboratory or test purposes, its commercial value is little because even the slightest leak causes off-gauge rolling. Other calibrated devices, placed under the screws, in addition to the fact that they must be designed to carry the full rolling load and hence are necessarily costly, give rise to inconvenience in roll changing, and to inaccuracy due to inexact relocation after the changing of the rolls. Another disadvantage of placing any device between the screws

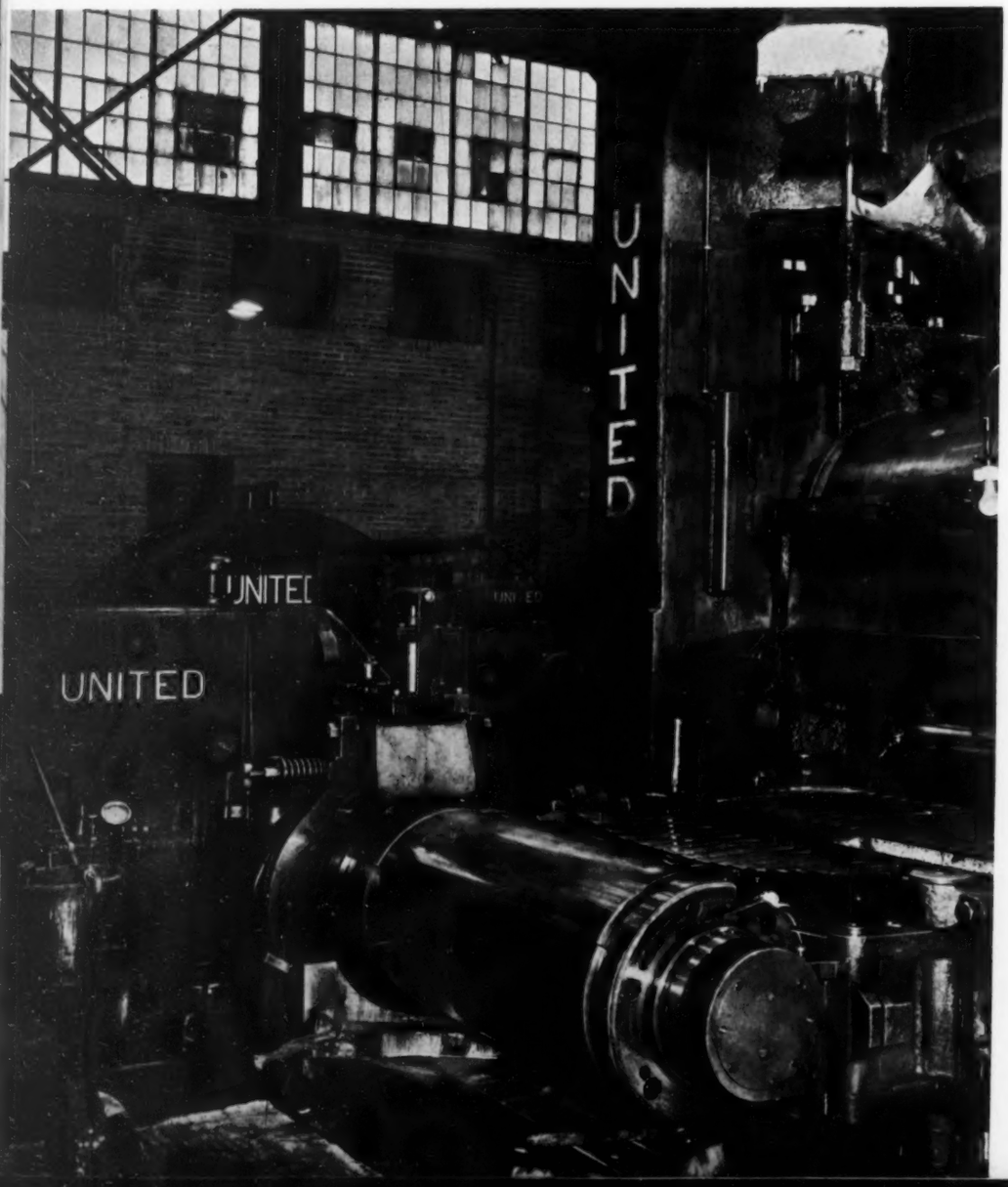


Fig. 1
View of Pressure Meter welded on the housing of a rolling mill.

and the chocks is that it necessitates a correspondingly higher mill, meaning longer posts, and thus doubly adds to the mill flexibility, which is always being held to a minimum for the reasons previously described.

A commercially desirable instrument should be one that indicates at usually one or two locations (for instance, both control benches on a reversing cold reducing mill) and records at still another location—say, the mill superintendent's office. It should be rugged, sensitive, and easily adjusted. Such an instrument has been recently devised and successfully applied, which utilizes the stretch of the housing posts as the actuating means.* The stretch of the posts over a properly chosen gauge length is utilized to change the air gap of an induction micrometer. This induction micrometer**consists of two relatively movable armatures, one of which carries coils forming two legs of an a-c bridge, the other two legs being formed by a potentiometer located at the convenience of the operator. In its preferred form, such an installation comprises two sets of equipment—one for each screw—and uses two indicating meters and a recording meter connected in series across the bridge. By the proper proportioning of the mechanical and electrical parts, housing elongations of the order of .00001 in. can be observed. For the usual housing proportions, where for reasons of rigidity, the maximum tension stress in the housing post due to the rolling loads varies from 1000 lb. per square inch to 2000 lb. per square inch—this means load variations of one-half of one percent can be detected. For these instruments, the electrical-meter readings are linearly proportional to the rolling loads. The voltage applied to the bridge must be kept constant, for which purpose, a voltage regulator or a synchronous-motor generator is used.

In order that the meters be made to read the screw or bearing load directly in pounds, or rather hundreds of thousands of pounds, a calibration of the mill must be made. This involves straining the mill under a known load, and marking the meter reading accordingly. This is performed easily in either of two ways: By placing a hydraulic jack between the back-up rolls (with the work rolls removed) of sufficient capacity to strain the mill in the neighborhood of its normal load; or by placing two jacks between the screw points and the bearing chocks. The latter method requires that there be sufficient space provided in the mill when constructed to permit the insertion of the jacks. This objection is eliminated in the first method, where only one jack is utilized, being placed on the center line of the pass. Saddles are placed between the jack and the rolls, being made to fit the roll diameters exactly, so that only low contact stresses are set up. As to the roll itself, the neck stresses are the same as though the mill were loaded by steel being rolled, and the roll body stresses are so low with respect to the neck stresses that they need not be considered.

That a static calibration of the mill, with no torque being applied (corresponding to that required to drive

★ Developed jointly by W. Messinger, Messinger Bearings, Inc. and M. Stone, United Engineering & Foundry Company

★★ Trans. A. S. M. E.—A. P. M. Vol. 2, No. 2, 1935

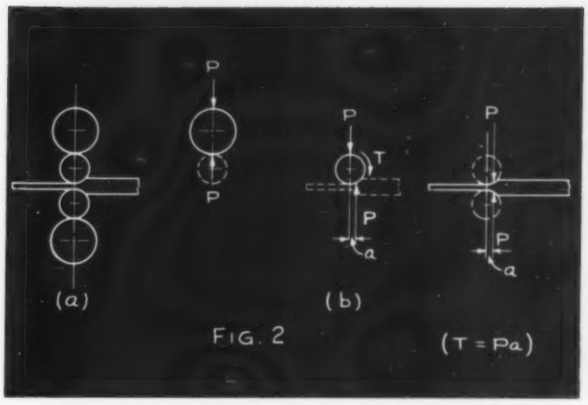


Figure 2—An equilibrium study of the rolls of a 4-High mill showing how the roll pressure is always central with respect to the housing posts, i. e., the force acts along the axis of the screws.

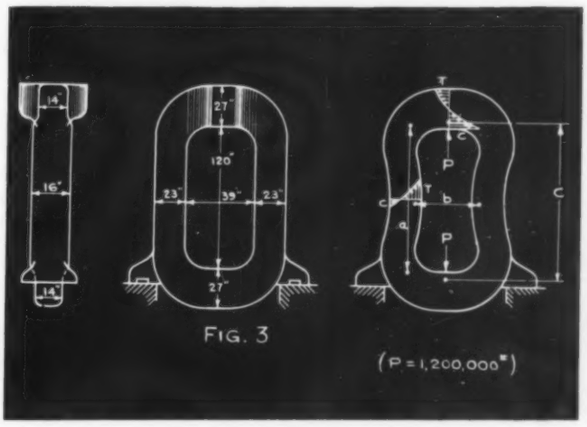
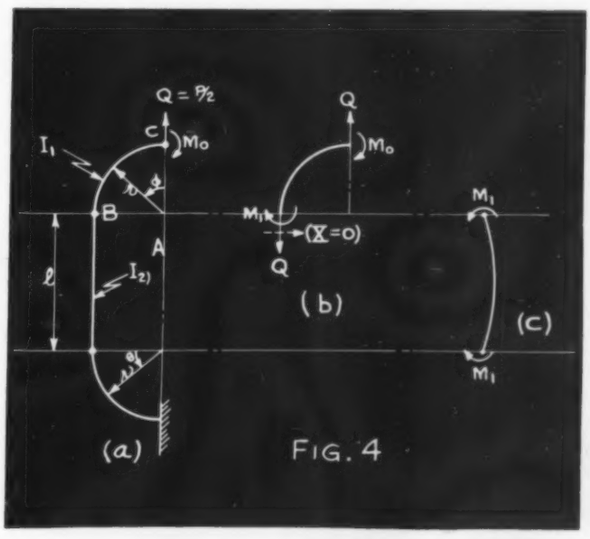


Fig. 3—This shows the distortion of a rolling mill housing under the normal separating forces set up in rolling.

Fig. 4—An isolation diagram showing the distortion of a rolling mill housing under the rolling load. The housings are considered as giant links, made up of two semicircular ends, with straight sides.



the mill) holds equally as well for all combinations of load and torque when rolling is shown in the Appendix. No matter what degree of reduction is being taken, and no matter what the relation of work roll diameter to strip gauge being rolled—thus throwing the resultant rolling pressure on the steel considerably off the center line of the work rolls—the reaction against the back-up rolls is always vertical, and exactly along its center line, and hence the center line of the mill.

The question as to the best location of the gauge bar which serves to concentrate the stretch of the housing over a length corresponding to that of the bar down to the induction micrometer proper is also discussed in the Appendix. It is shown that the normal distortion of the housing under the rolling loads is such as to decrease the distance between the posts, placing the inner surfaces in tension due to the combination of pull and bending, while the outer surface may be in low tension or even compression, depending on the relative magnitudes of the average tension stress and the pure-bending stress. In any event, it is appreciated that the strain will be very small, and hence this surface would be the least desirable location for the gauge. On the other hand, the inner surface has the greatest strain, and would be the most desirable location but for one objection. If for any reason, during the life of the mill, the bearing chocks should be changed, and inadvertently made close fitting, or if in any other manner a real restraint should be introduced against lateral contraction of the housing posts, then the magnitude of the bending moment would be altered, and hence the strain at the inner surface, for a given load. By locating the gauge on the center line of the post, i. e., the neutral axis, this possibility is guarded against since the strain at this point is due to the average tension only, and independent of the bending moment.

For new mills, provisions are made whereby the housing posts are slotted to receive the entire gauge equipment, a flush surface being obtained by use of a heavy inset cover, and a neat unobtrusive construction is obtained. The cover is made oil tight, the gauge bar over its entire length being surrounded with a light machine oil so that the bar and its immediately adjacent housing are maintained at the same temperature. For mills already built and installed, where slotting of the housing posts is difficult, the gauge bar is preferably attached on the outside of the housing, the entire apparatus being enclosed by a heavy cover, welded to the housing, and carrying a thick insulating layer and an oil bath within, see Fig. 1. For accurate and easy adjustment of the air gap, a mechanical micrometer head is provided, built together with the gauge equipment within the housing post. For further ease of adjustment, such as zero shift, or the like, the potentiometer is mounted at the operator's convenience on the control bench.

Instruments of the type described in this paper have been installed in many mills to date, and with their low cost, their compactness and unobtrusiveness accomplished, their utility established—it is expected that a large number of the mills in the future will be built with such apparatus an integral part of the mill equipment.

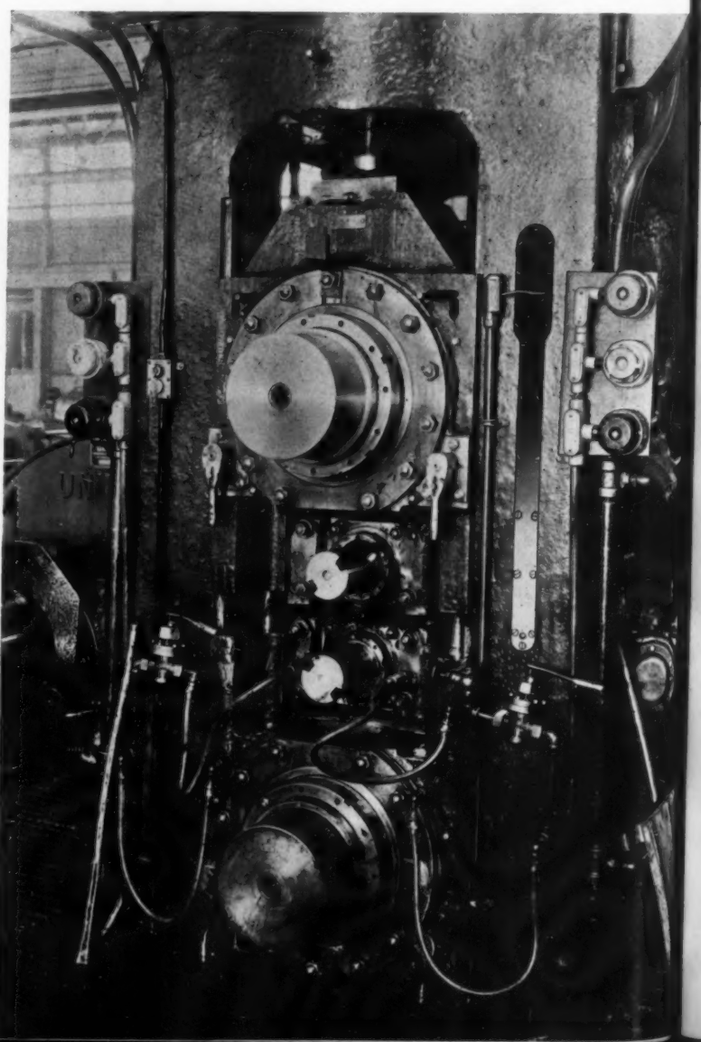
Whereas we have discussed thus far the indication and recording of mill pressures—the control of pressures should come in for its share of consideration. Where mill pressures for a number of stands are indicated on one master board—such as in the control pulpit for the finishing end of a hot mill, say—it is proving expedient to supply contact making indicating instruments. Their function is to sound an alarm or light a lamp, or both, to call attention to an excessively loaded mill housing. Although it has not been deemed necessary to date, an opportunity exists for automatic control of screw pressures. With the load indicator acting through a relay, practically instantaneous gauge correction could be accomplished. However, due to the fact that there are bound to be some variations in material physical properties from point to point in the strip, much useless and undesirable operation of the screwdown mechanism might properly be involved.

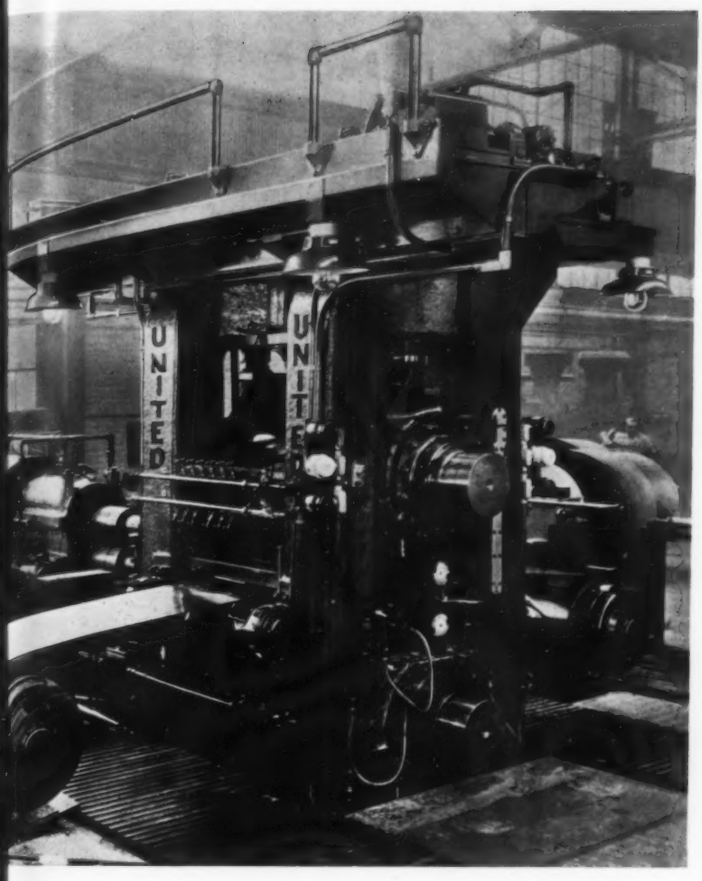
APPENDIX

Rolling Mill Housing Distortions

For 4-high mills, with both working rolls driven, the roll pressure is always central with respect to the housing posts, i. e., the force acts along the axis of the

Closeup view of Pressure Meter.





Pressure Meter designed into the housing post of a rolling mill.

screws. This is apparent from an equilibrium study of each roll separately in Fig. 2. For mills of the usual design where the work rolls and back-up rolls operate essentially along a single vertical center line, it is obvious that there can be no horizontal forces, other than the slight ones due to friction of the steel being pulled over the tables. For if this were not true, a free horizontal acceleration of the strip would be involved.

The distortion of a rolling mill housing under the normal separating forces set up in rolling are as indicated in Fig. 3. In fact, Fig. 3a and 3b show the dimensions of an early mill housing which was carefully tested for distortion. Following the steps of the analysis, the distortions of the housing dimensions a, b, and c are understood to be elongations for the first two, and a lateral contraction for the third, and that the stresses in the housing are also as shown.

The distortions of a mill housing under the rolling load are similar to those of a giant link, made up of approximately two semicircular ends, with straight sides. In order to obtain a quantitative idea of the distortions, consider the isolation diagram, Fig. 4. In order to evaluate the intermediate reaction M_0, and hence M_1, the Theorem of Virtual Work gives, where only the stored energy of bending is considered, i. e., $\frac{\partial U}{\partial M_0} = 0$, where

$$U = \int_0^{\pi/2} \frac{\left(M_0 - \frac{Pr}{2} \sin \Phi\right)^2 r d\Phi}{2\,EI_1} + \int_0^{l} \frac{\left(M_0 - \frac{Pr}{2}\right)^2 dx}{2\,EI_2} + \int_0^{\pi/2} \frac{\left(M_0 - \frac{Pr}{2} \cos \Theta\right)^2 r d\Theta}{2\,EI_1} \qquad (1)$$

This leads to

$$M_0 = Pr \left\{ \frac{1 + \frac{I_1 l}{2 I_2 r}}{\pi + \frac{I_1 l}{I_2 r}} \right\} \qquad (2)$$

and

$$M_1 = Pr \left\{ \frac{\pi/2 - 1}{\pi + \frac{I_1 l}{I_2 r}} \right\} \qquad (3)$$

Now the vertical elongation of the top yoke, i. e., point B with respect to point C is given by $\frac{\partial V}{\partial Q}$ where V = strain energy of one-half of the top yoke

$$V = \int_0^{\pi/2} \frac{[M_1 - Qr\,(1 - \sin \Phi)\,]^2\, r\, d\Phi}{2\,EI_1}$$

To obtain total elongation of the housing window, Δ, we have

$$\Delta = 2 \frac{\partial V}{\partial Q} + \frac{Pl}{2\,EA} \qquad (4)$$

To obtain the maximum lateral contraction of the housing window, δ, we have

$$\delta = 2 \left[\frac{\partial V}{\partial X} + \frac{M_1 l^2}{8E\,I_2} \right] \qquad (5)$$

Carrying out the indicated calculations for a housing that has been tested, and whose dimensions are given in Fig. 4, where

$I_1 = 2300$ in.^{4}	$r = 31$ in.
$I_2 = 1600$ in.^{4}	$l = 85$ in.
$A = 368$ sq. in.	$P = 1{,}200{,}000$ lb.
$E = 30 \times 10^6$ lb. per sq. in.	

The following are the test and calculated results:

Change in dimensions

	Test	Calc.
a	+ 0.008	+ 0.009 in.
b	— 0.023	— 0.027 in.
c	+ 0.022	+ 0.021 in.

Calculation stresses

Yoke	— 10000 lb. per sq. in. Comp.
	— 8000 lb. per sq. in. Tension
Post	— 3700 lb. per sq. in. Tension
	— 500 lb. per sq. in. Comp.

Of course, the calculations above have been simplified by neglecting the energies of shear and tension in figuring the indeterminate reactions—and the housing form has been idealized into an entirely symmetrical link, but the closeness of test and calculation justifies the procedure.

CIRCULAR HEATING FURNACES

THEIR DEVELOPMENT FOR INGOT HEATING

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Salem Engineering Company
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Paper presented before the A. I. & S. E. E. Spring Engineering Conference, Youngstown, Ohio, April 22, 23, 1936

▲ THE circular furnace to be discussed in this paper is the result of two simultaneous and somewhat distantly related developments in the steel industry. One is the progress in metallurgy of steel making, and the other is the development of heating equipment for the manufacture of steel articles.

In the past ten or fifteen years the problems of the steel mill operator have become more and more complicated and difficult, as the result of the development of many different kinds of alloy steels. Each of these alloys requires special treatment of an exacting nature, which it is becoming more difficult to accomplish in the old fashioned furnace or soaking pit.

In the same period of time, the automobile makers and many other good customers of the steel mills have been struggling with the problems incident to the utilization of these new alloys. The heat treatment of these steels for finishing is even more exacting than the heating involved in their making, and the growing problems have produced a new industry—the industrial furnace builders.

These companies are specialists in heating, long employed by the steel finishing industries, and more recently by the steel mills.

As a result of the separate progress of steel mill metallurgy and the consumer's use of the product, we find today in many mills the difficulty of making sensitive steels with crude heating equipment, while next door is a variety of furnaces used in the finishing processes and incorporating new ideas which would lighten the mills' worries if investigated and properly applied to their problems.

Looking critically at soaking pits now in use, the furnace engineer whose experience has been in the heat treatment for finishing processes and who knows little about steel mills, is surprised at the large opening around the furnace covers of almost all pits. He knows that a loose door or cover which permits hot gases to escape will warp and burn away rapidly, but upon investigation he finds a high stack with sufficient draft to prevent leakage of hot gases by pulling in air. This all means wrong to our furnace engineer who has built successful doors and covers for forging furnaces at higher temperatures and who builds larger and hotter furnaces without any stacks, because his customers cannot permit excess air in their furnaces and because he knows that a stack is difficult to control.

The draft in a pit 8 feet deep at 2400° F. is about $\frac{1}{16}$" water, and in a stack 125 feet high is about $\frac{5}{16}$" water. To balance these two strong forces manually is impossible, and it is even difficult to do it mechanically. Another striking observation of the soaking pit layman is the large heat losses when the covers are opened wide to draw an ingot at the back end. A tremendous heat saving can be demonstrated by calculation and by experience to result from two way operation.

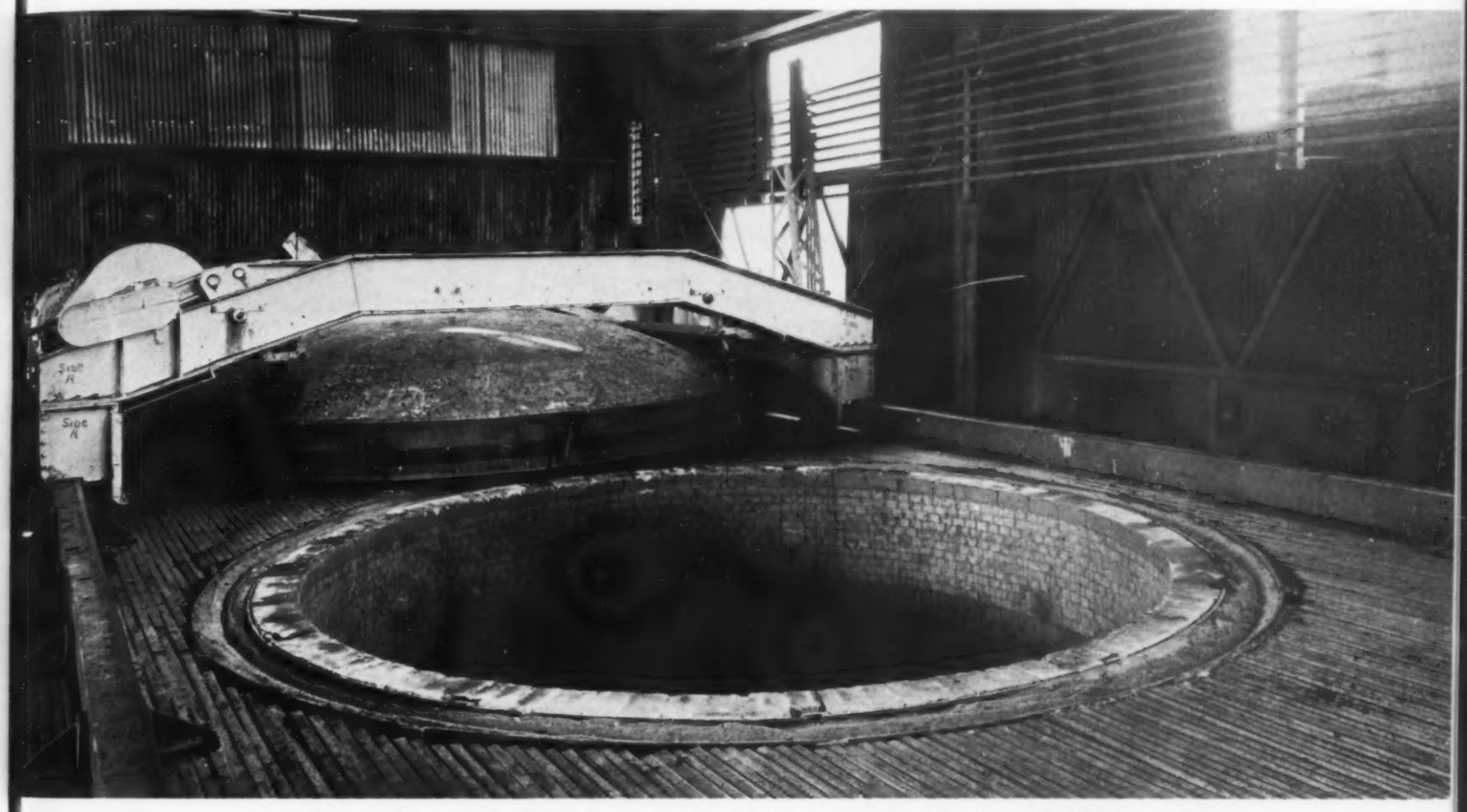
The shape of pits and arrangement of heat sources is also interesting. The necessity for moving ingots from the corners before finally drawing, suggests the shape without any corners—a circle. A multiplicity of burners is standard design in finishing equipment, but rare in soaking pits.

M. H. MAWHINNEY

The lack of temperature control on most pits is hard to understand, because all forging shops making parts of alloy steel for automobiles and other requirements, have come to rely upon thermocouples and automatic temperature controllers for furnaces frequently as large and always as hot as a soaking pit. The use of these comparatively simple devices eliminates the necessity for attention to the furnace operation, and permits the exact reproduction of temperatures and cycles for any number of heats, as well as preserving a record of these conditions.

on those drawn from the usual pit and that the amount of bottom making is very much less.

All soaking pits are designed with heavy regenerators or recuperators, and depend on hot air for combustion. Under these conditions the repeated heating of cold ingots slows up, or "kills" the pit operation. The circular ingot furnaces operate with cold air and are entirely independent of the temperature in the exhaust chimney, with the result that heat after heat of dead cold ingots may be heated with no change in the speed of heating.



Details of the circular furnace may be gleaned from a perusal of the above illustration

Regarding atmosphere in soaking pits, we have already remarked on the common condition of air infiltration. This condition, as well as the combustion obtained by crude burner and mixing equipment on many pits, result in an atmosphere which would be entirely unsuitable to the finishing of steel. The necessity for proper atmosphere for these processes has resulted in burner equipment to automatically maintain a given fuel-air ratio, and by using such equipment in conjunction with furnaces in which a positive pressure is at all times maintained, it is possible to accurately control the chemical action of the furnace atmosphere on the steel. On the circular ingot furnaces, the same equipment is used, and the analysis of the atmosphere in the furnace is consistently maintained at 0.5 to 1.0% CO with no oxygen. The results are that the scale on the ingots is considerably less than

In the endeavor to incorporate all of the good points of the furnace design followed in the heat treating processes for finishing of steel, the circular furnace for ingot heating has been developed.

A summary of advantages of this new furnace includes:—

1—Elimination of cold corners.
2—Symmetrical heat application to all ingots.
3—Close control of temperature and temperature and temperature uniformity.
4—Minimum pit depth resulting from bottom firing.
5—Radiation reduced by two-way cover operation.
6—Positive furnace pressure with sealed cover and no stack.
7—Automatic control of fuel-air ratio.
8—Automatic temperature control.
9—Rapid heating of repeated charges of cold ingots.

(Discussion on following page)

DISCUSSION

PRESENTED BY

M. J. CONWAY, Fuel Engineer, Lukens Steel Company, Coatesville, Pa.

M. H. MAWHINNEY, Consultant, Salem Engineering Company, Salem, Ohio.

P. M. OFFILL, Vice President, Amsler-Morton Company, Pittsburgh, Pa.

F. E. LEAHY, Fuel Engineer, Youngstown Sheet and Tube Company, Youngstown, Ohio.

A. G. WITTING, Chief Engineer, Carnegie-Illinois Steel Corporation, Gary Works, Gary, Ind.

J. L. MILLER, Assistant Chief Engineer, Carnegie-Illinois Steel Corporation, Youngstown, Ohio.

M. J. Conway: I note from Mr. Mawhinney's description of the pit operation that the hot ingots charged were of uniform size and I would like to know what their experience has been with ingots of varying sizes and shapes charged into the same pit, especially slab ingots. Mr. Mawhinney also related that there were no recuperators or regenerators on the pit as at present installed, which leads me to inquire what is the relative fuel consumption when compared with other types of regenerative and recuperative soaking pits. Has Mr. Mawhinney had any experience with oil as fuel on this new pit, and has he any data showing difference of efficiency between gas and oil as a soaking pit fuel?

M. H. Mawhinney: Referring to the first question as to the different sizes of ingots in the pit, in experience with the pits to date, I have seen ingots of many different sizes charged. I think we might refer that to someone here from Youngstown to answer more definitely. The ingots which we have heated to date are from about 18 x 18 inches to 21 x 47 and in some of the future pits we are planning to heat up to 23 x 56 or 24 x 56, slab ingots.

The economy of the pit without recuperators or regenerators depends on the relative amounts of cold steel and hot steel. The information we have to date indicates that that economy is somewhere in the neighborhood of 1.4 million B.T.U., which of course is higher than the regenerative or recuperative pit. That data is being assembled more accurately, but that is what it appears to be from the information to date.

A test has been run on this furnace with oil for a duration of a week or ten days with good heating of the ingots. The pits which are now under construction are to be fired with oil, nine pits to be fired with oil based on the test which was made to prove whether it could be done. The test was not of sufficient duration to get reliable figures on the fuel economy, but it appears to be about the same as with gas. The same number of burners were used and the combustion was about the same as that with gas burners, no apparent difference in it and the analysis with gas.

P. M. Offill: This paper on the round pit has been very interesting and well presented.

I very much regret that I was unable to accept the invitation of the Society to present a paper on The Amsler-Morton bottom fired pit which was due to the lack of complete operating data which we felt was necessary before giving a paper before this group.

With this in mind, I feel at liberty to give you a few facts regarding The Amsler-Morton soaking pit installed in the Pittsburgh district.

The soaking pit is 12' 3" square and holds 12 Bessemer Ingots 19 x 21 x 68. The heating time is 2 hours; the fuel used is natural gas. The fuel consumption has never been higher than 340,000 B.T.U.'s per gross ton, and we expect to go considerably lower. Bottom making is done once a week, which makes it obvious that there can be no washing, and considerable reduction in scale loss results.

The Association has asked me to present a paper on this soaking pit at the September Meeting, at which time I will present complete operating data.

F. E. Leahy: About a year ago, our company decided to pioneer with the Salem Engineering Company in the installation of the first of the so-called circular type ingot heating furnaces at our Campbell Works. Previous to this, we had some experience with a similar type of furnace in our heat treating department. The features of the heat treating furnace that particularly attracted us were the simplicity and accuracy of the temperature and atmosphere control. We thought that it was just as desirable to have the same accuracy of control in the heating of ingots.

Since the installation, we have had the opportunity of heating all grades of Bessemer and Open Hearth Steel and various sizes of ingots from slabs to squares. The pit which is 11 ft. in diameter normally holds 9—21" x 23" square ingots, or 5—21" x 47" slab ingots. The pit was originally started—using coke oven gas and blast furnace gas mixed for fuel. A special test covering a number of weeks was run, using a heavy grade of oil for fuel.

During the period of the test, 40% of the ingots were charged into the pit cold and 60% hot. The fuel consumption for this period was approximately 1,430,000 B.T.U.'s per ton. The rate of heating of cold steel only was 2.8 tons per hour, and on steel only—7.47 tons per hour.

The time for heating hot steel varied from 3 to 4 hours, and for cold steel—from 8 to 9 hours.

A feature of the pit noticed a short time after it had been placed in operation was the manner in which the pit could be kept continuously heating cold steel. This was one of the outstanding features over the other pits in use in this same department. It was not necessary to transfer this type of operation to another pit in order

to bring the steel to a satisfactory rolling temperature.

The operations of the pit today covering a wide variety of steel have been very satisfactory.

A question was asked why we had not installed a recuperator on this pit. Inasmuch as we were copying a heat treating furnace in principle, we confined the designs of the pit as closely as possible to that used in the heat treating furnace, where the automatic control had been so satisfactory, as well as the operation. However, at a later date, further pioneering may be done through the use of a recuperator. We can then determine if the economy from that device will justify the cost of the installation over that now in use.

A. G. Witting: As I understand the description of this furnace, it is provided with fourteen burners and that 34 ingots are charged at one time, the ingots leaning against the furnace wall. It seems to me that then some of the ingots are directly opposite a burner and very close to it so that the flame will be impinging against one side of the ingot. Will such a condition not be detrimental?

M. H. Mawhinney: There is a travel of four or five feet before the flame comes in contact with the ingots due to the design of the interior of the pit.

A Member: Are there any scale loss figures for that heating?

M. H. Mawhinney: The information we have to date indicates one-half the scale loss of the average regenerative pit. This would seem logical because of the fact at no time is any air drawn into the pit and at all times the ratio of air and gas is kept constant. Observation of most pits in operation shows quite a draft of air, whereas this one never has any infiltrated air. The furnace itself is tight, kept under pressure at all times, and the air that enters it as combustion air with the fuel is under control. To date the scale is obviously lighter on these ingots.

J. L. Miller: Do you have a slag opening in the bottom?

M. H. Mawhinney: We have no slag opening in the pit. The first one was made without them, I would say maybe as a result of dumbness, and no further ones have required the holes. Anything that is removed from the pit is taken through the center opening which serves as the flue. It drops into a chamber below for removal. That material then is taken out. There has been no running slag in the pit that I know anything about in any of the installations, no liquid produced, no doubt, because the temperature is always held to a certain maximum. It never goes over 2450. That is at the hottest part of the pit. It is held there all the time. The scale produced is small. The result seems to be no washing of the ingots, no bright spots on the ingots resulting from the washing. The bottom is removed not more than two times a week and seems to be an operation requiring about half an hour, operated through the opening by moving the cover off. Perhaps Mr. Leahy might add something to that.

F. E. Leahy: I believe what you said is correct. Due to the temperature control used, we avoid running any cinder in the pit. Twice a week we rake out the coke breeze and replace it in the bottom.

Due to our control of the furnace atmosphere, we maintain the scale on the ingot in the pit, which avoids another cause for the formation of cinder. Of course, such close automatic control in any pit will produce the same results.

D. M. PETTY AWARDED INSTITUTE MEDAL

D. M. Petty, Superintendent of the Service Division, Bethlehem Steel Company, Bethlehem, Pa., was awarded the American Iron and Steel Institute medal for his paper "The Economic Importance of the Replacement of Obsolete Equipment in Steel Mills" which was presented before the Institute in May 1935. The award was made at the annual banquet of the Institute held May 28, 1936.

Mr. Petty is a past president of our association and has contributed many articles before the society. The entire membership of the association joins with us in congratulating Mr. Petty upon the signal honor that was conferred upon him by the American Iron and Steel Institute.

D. M. PETTY

▲ ▲ ▲ ITEMS OF INTEREST ▲ ▲ ▲

Julius E. Graf, formerly chief engineer of the American Sheet and Tin Plate Company, which was merged with the Carnegie-Illinois Steel Corporation has been appointed assistant chief engineer of the company which was effective June 1.

Mr. Graf had been associated with the American Sheet and Tin Plate Company since 1911.

JULIUS E. GRAF

W. W. Knight, Jr., has been appointed sales engineer for the Morgan Construction Company in the Pittsburgh district.

Mr. Knight after studying mechanical engineering at Cornell University, followed by a course in Business Administration at Northwestern University, became plant engineer of the Roth Rubber Company at Cicero, Illinois in 1928. In 1929 he entered the engineering department of the Timken Roller Bearing Company at Canton, Ohio, and two years later, in 1931, was made sales engineer for the New England district with headquarters in Boston. He held this position until March 1936.

W. W. KNIGHT, JR.

Mr. H. H. Wood will remain in charge of the Morgan Construction Company's Pittsburgh office, which will soon be moved to more spacious quarters at 2028 Koppers Building.

George E. Totten, who, June 1, was appointed manager of sales of the tin plate Division of the Carnegie-Illinois Steel Corporation, has had a very active career in this branch of the steel industry, having served with the Jones & Laughlin Steel Corporation for a great many years in various capacities, largely in tin plate sales. In 1931 Mr. Totten was appointed sales manager of the tin plate division of Republic Steel Corporation, where he remained until accepting this new position with Carnegie-Illinois Steel Corp.

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Avery C. Adams, who has just been appointed manager of sales of the Carnegie-Illinois Steel Corporation's Sheet Division, after finishing at Yale, joined the Trumbull Steel organization, working up through the ranks to the position of assistant general manager of sales, following which he became manager of the tin plate sales department of the Republic Steel Corporation, and prior to coming to Carnegie-Illinois was Vice-President in charge of sales of the General Fireproofing Company.

▲

Clarence D. King, as announced by R. H. Watson, Vice President in charge of operations, United States Steel Corporation, has been appointed chairman of the blast furnace committee to succeed the late W. A. Forbes.

▲

C. M. Tate has resigned from his position with Askania Regulator Co. to join Hagan Corporation, Pittsburgh, Pa. Mr. Tate, for the past two years with the Askania Regulator Company and with H. A. Brassert Co. (who formerly handled the Askania Regulator) specialized in the application of combustion control to metallurgical furnace in the steel mill industry. His work with Hagan Corporation will be principally along similar lines, handling the application of improved types of Hagan oil-operated and air-operated regulator equipment for control of air-fuel ratios, furnace pressures, etc. to heating furnaces, open-hearth furnaces and soaking pits.

Mr. Tate will have his headquarters at Pittsburgh but will cooperate with the various Hagan Corporation offices in other territories in contacting the steel mill industry.

A. H. Frauenthal, as announced by the Bantam Ball Bearing Company, has been made the vice-president and general manager of the company. Mr. Frauenthal, who was assistant general manager, succeeds Mr. Karl Herrmann in his new capacity.

Mr. Frauenthal has been with the Bantam organization since 1930. Since that time he has spent several years in the field as sales engineer in various parts of the country. Mr. Frauenthal was finally made manager of the steel mill division and was in charge of sales, engineering and manufacturing up to the time of his appointment as assistant general manager of the Company.

A. H. FRAUENTHAL

Although Mr. Herrmann is retiring from his major duties as general manager in line with plans made when he sold the Bantam plant to The Torrington Company, his services are being retained as a Consulting Engineer. Coming to Bantam in 1929 as Vice President and General Manager, the company, under his direction, has increased its business to where it is now running ten times the average of the previous five years.

Before coming to Bantam, Mr. Herrmann had had over 30 years experience in engineering. Approximately 20 years of this was with the Studebaker Corporation, during the last six years of which he acted as consulting engineer for that organization.

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C. E. Nuckels has been appointed the vice president in charge of all sales and engineering for the Post-Glover Electric Company of Cincinnati, Ohio. Mr. Nuckels for the past ten years has been in the capacity of chief engineer for the company.

▲

Harry S. Peck has joined the sales staff of the Baker Industrial Truck Company with offices located at 407 South Dearborn Street, Chicago. Mr. Peck will be associated with Blake Hooper who has been district representative for Baker for the past several years.

Edward J. Hanley, formerly assistant superintendent of the wire and cable department of the Schenectady Works of the General Electric Company, has been appointed secretary of the Allegheny Steel Company which was effective on May 25, 1936.

Mr. Hanley, a native of Whitman, Mass., was graduated from Phillips Andover Academy in 1920 and obtained a B.S. from Massachusetts Institute of Technology in 1924, and in 1927 a master's degree in business administration from the Harvard graduate school of business.

EDWARD J. HANLEY

Mr. Hanley entered the employ of General Electric in 1927 as a member of the factory training course, and the following year was transferred to the staff of the Schenectady works accountant. In 1931 he became assistant to the auditor of works accounts, and in 1934 was appointed to his position in the wire and cable department.

▲

Frank B. Powers has been appointed manager of the Railway Engineering Department to fill the vacancy caused by the recent death of Claude Bethel, according to an announcement by A. C. Streamer, Manager of the Transportation Division, Westinghouse Electric & Manufacturing Company. At the time of his appointment, Mr. Powers was in charge of the design of Westinghouse d.c. traction motors including those for the new President Conference Committee street cars and the new single motor trolley coaches.

Following his graduation from the University of Illinois Mr. Powers joined Westinghouse attending both engineering and design School as part of the Company's Graduate Student Course. After this intensive engineering training he was assigned to help service the 6000 hp. Virginian Railway locomotives, where he got his first practical experience in the electric traction field. On his return to Westinghouse's headquarters at East Pittsburgh, Mr. Powers entered the heavy traction section of the Railway Engineering

Department specializing on the design of motors for the Pennsylvania Railroad locomotives. In January 1935, he was promoted to section engineer of all d.c. traction motors, which position he held until this new appointment.

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Hans E. Melin has joined the staff of The Wean Engineering Company, Inc. of Warren, Ohio as sales engineer. Mr. Melin is a graduate of Chalmers Technical University, Gotenburg, Sweden and has just recently returned from abroad where he was

HANS E. MELIN

associated with The Wellman Smith Owen Engineering Corporation of London.

Prior to his going abroad in 1935 Mr. Melin had been connected with The Aetna-Standard Engineering Company of Youngstown, Ohio in a sales and engineering capacity for a period of seven years.

▲

Charles Wilbur Bennett, last president of the American Sheet & Tin Plate Co. resigned prior to its absorption by Carnegie-Illinois Steel Corp. on June 1.

He gained recognition throughout the steel industry during his 40 years association with the American Sheet & Tin Plate Co. and its predecessors for important improvements in production he helped to introduce.

Mr. Bennett began his career with the American Tin Plate Co. as a mechanical engineer. In 1906 he became assistant to the president of the American Sheet & Tin Plate Co. His election to the office of vice president in 1925 was followed in 1933 by his elevation to the presidency, succeeding E. W. Pargny.

▲

J. Carlisle MacDonald has been appointed to the executive personnel of the United States Steel Corp., New York, as an assistant to Myron C. Taylor, chairman of the board in respect to public relations. He assumed his new duties June 1. Mr. MacDonald was educated at St. Louis University, Stevens Institute of Technology and in England. He engaged in newspaper work for many years, and more recently served as public relations counsel for Guggenheim Bros., New York.

Earl M. Richards, assistant to the vice-president in charge of operations of Republic Steel Corp., and an active member of the A. I. & S. E. E., has been elected vice-president of the American Management Association in charge of the production division. He was graduated from Bucknell University in 1913 with the degree of bachelor of science in electrical engineering. During the War he served as technical adviser for the Fuel Conservation Committee of Western Pennsylvania and as special engineer for the United States Railroad Commission. In recognition

EARL M. RICHARDS

of his war-time services he was given an honorary degree of electrical engineer by Bucknell University in 1919 and in 1934 he was elected to the board of trustees.

Mr. Richards was affiliated with the Westinghouse Airbrake Co. from 1913 to 1919 as assistant to the chief engineer and later as assistant to the manager of engineering. From 1920 to 1925 he served as a consulting electrical and mechanical engineer in the East and in the latter year went with the Jones & Laughlin Steel Corp. as chief industrial engineer of its Aliquippa Works. In 1930 he became chief industrial engineer of the Republic Steel Corp. and subsidiaries and in 1935 was made assistant to the vice-president in charge of operations. He is a member of the American Iron and Steel Institute, American Society of Mechanical Engineers, American Institute of Electrical Engineers, and of the American Management Association, being also a director of the latter organization. He served for two terms as president of the Youngstown section of the American Society of Mechanical Engineers. He is co-author of a 300-page volume covering some of the investigations he made during his connection with the United States Railroad Administration and articles written by him have appeared in technical publications in this country and Europe.

∴ OBITUARIES ∴

John C. Williams, president of the Weirton Steel Company, died suddenly on Monday June 1 at his home in Weirton, W. Va. Although his health had been failing for the past year, he had continued his active interest in business affairs and spent a few hours in his Weirton office the previous Saturday.

Mr. Williams was considered one of the most able operating steel executives in the country. Starting as a boy of 15 in Wales 47 years ago, he had spent his entire career in the steel industry. He was born in Kidwelly, Wales, on March 31, 1876. He obtained his education in the public schools of his native country, and his first experience in the steel business was gained by working under his father in a Welsh tin mill.

JOHN C. WILLIAMS

Mr. Williams advanced very rapidly and while still in his teens he received and accepted an offer to take charge of a steel plant in Piombino, Italy, a post which he held for about two years. In 1897, at the age of 21 years, he came to the United States and shortly after his arrival here became superintendent of the Champion Iron and Steel Company at Muskegon, Michigan.

In 1903 he became assistant superintendent of the plant of the American Tin Plate Company at Monessen, Pa. This position marked a turning point in his life for it was there that he met Mr. Ernest T. Weir, then manager of the plant, with whom he was to be associated for the remainder of his life.

In 1905, Mr. Williams participated with Mr. Ernest T. Weir, Mr. David M. Weir, Mr. J. R. Phillips, and several others in the formation of the Phillips Sheet and Tin Plate Company, at Clarksburg, W. Va., which was to grow into the Weirton Steel Company. Mr. Williams was in charge of operations at this plant and later occupied a key position in the building and operation of the Weirton plant.

Mr. Williams spent most of his time at Weirton during the past 26 years and saw his company grow from a single tin mill to a great integrated steel organization.

Mr. Williams became president of the Weirton Steel Company in 1929 at the time of its affiliation with other steel and ore organizations that joined in the formation of National Steel Corporation.

In addition to the presidency of the Weirton Steel Company, Mr. Williams held the following offices: Vice President, National Steel Corporation; President, Weirton Coal Company; President, Weirton Improvement Company; President, Midwest Steel Corporation; member of the board of directors of Great Lakes Steel Corporation, Michigan Steel Corporation; Hanna Iron Ore Company of Delaware, Hanna Furnace Corporation, and The Producers Steamship Company; President, Peoples Bank of Hollidays Cove and Vice-President, Bank of Weirton

▲

George R. Murphy, Manager of the Pacific Coast District of The Electric Storage Battery Company, Philadelphia, died on May 14th.

Mr. Murphy was 61 years old and had been in the employ of the Company for 36 years. He was widely known and esteemed on the Pacific coast, particularly in engineering circles and in the automotive trade.

▲

Frederick Rollin White, Chairman of the Board and former President of The Baker-Raulang Company, Cleveland, died at the Cleveland Clinic Hospital on May 13th after a very short illness.

Mr. White was the son of one of the founders of the White Sewing Machine Company. He was graduated from Cornell University in 1895.

At the time of his death, Mr. White was also a director in the American Ball Bearing Company, the Caxton Building Company and the Dynoc Company.

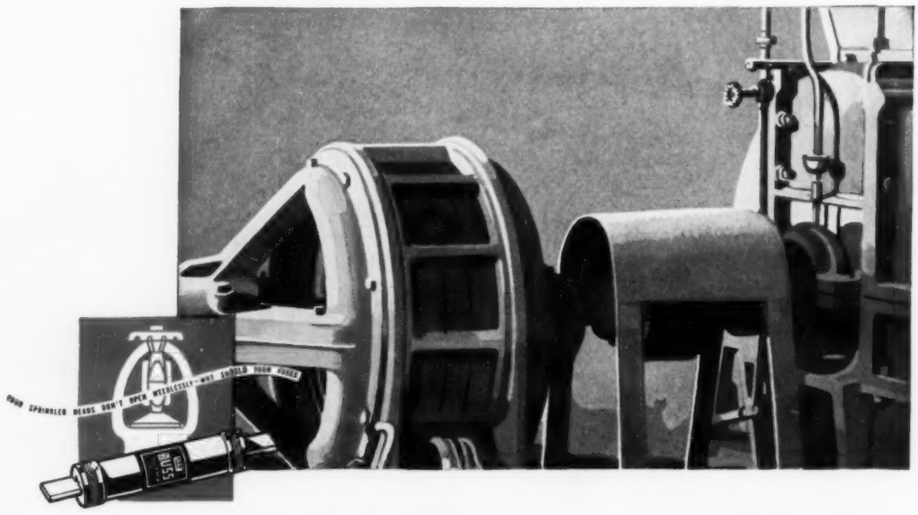
▲

Glen E. Guy, Cleveland district Representative for the Baker Industrial Truck Company, Cleveland, died at his home June 1st after an illness of a month.

Mr. Guy was graduated from Pennsylvania State College where he was a member of Phi Gamma Delta fraternity and was with the General Electric Company for several years having spent a year in their Shanghai office. In 1924 he became associated with Baker in the northern Ohio territory.

ADVERTISING PAGES REMOVED

FUSES MADE TO *protect*



"We cut fuse blows *from 3 per week to 1 in sixty days*"

HERE ARE THE FACTS . . . Mr. Arthur Lind, Chief Electrician of the Lumber and Veneer Plant of Elliott Bay Mill Co., Seattle, Wash. speaking, "The 188 amp. 440 volt motor on our fuel grinder was blowing ordinary 300 amp. fuses about three times per week. Two years ago we switched to BUSS Super-Lag fuses and cut our blows to not over one in sixty days. Furthermore, we can now trace these few blows to incorrect handling of the machine by the operator."

Like Mr. Lind thousands of other production-minded executives are finding that it pays a handsome profit to investigate fuses that • • • •

Benjamin F. Fairless *

PRESIDENT

CARNEGIE-ILLINOIS STEEL CORPORATION

FOLLOWING the recent announcement of the completion of the merger of the American Sheet and Tin Plate Company with the Carnegie-Illinois Steel Corporation, Mr. Fairless also disclosed the personnel of the corporation who will aid him in directing the affairs of the world's largest steel company. On the two following pages will be found the gallery of those assisting him in his task.

*Mr. Fairless' biography on 4th page of this section.

L. H. BURNETT,
Vice President

C. V. McKAIG,
Vice President and General Manager of Sales

J. H. McKOWN,
Assistant Vice President and Assistant General Manager of Sales

Upper Left

G. C. KIMBALL,
Executive Vice President, Chicago

W. I. HOWLAND, JR.,
Vice President, Western Sales, Chicago

J. W. HAMILTON,
Secretary

Lower Left

F. C. HARPER,
Treasurer

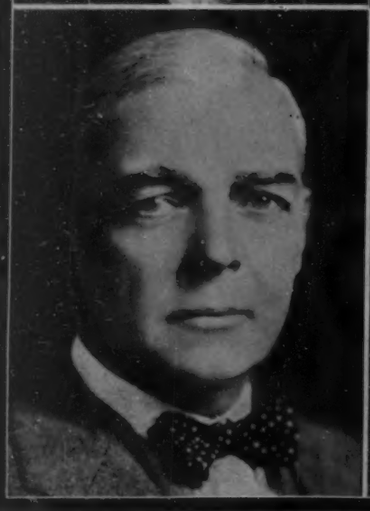
J. E. LOSE,
Vice President In Charge of Operations

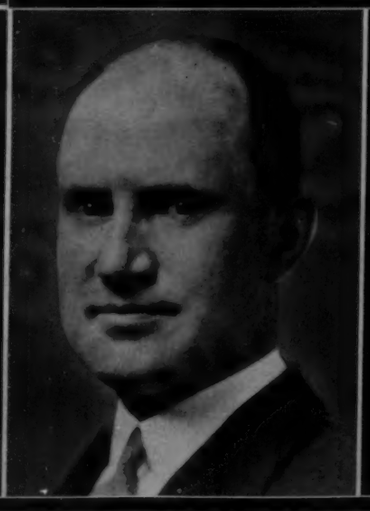
D. A. BARRETT,
Vice President

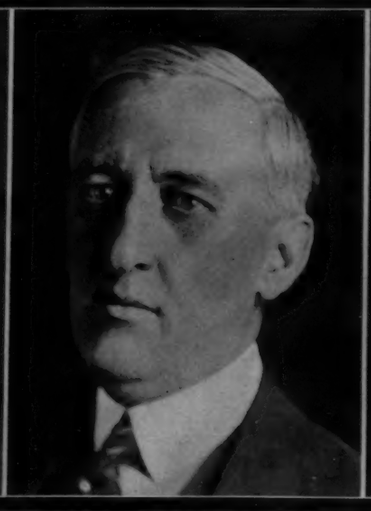
O. M. HAVEKOTTE,
Assistant Treasurer, Pittsburgh

E. B. HARKNESS,
Assistant Treasurer, Chicago

WM. DONALD,
Comptroller







WALTHER MATHESIUS,
Manager of Operations Chicago District

Right

H. G. McILVRIED,
Assistant Manager of Operations
Chicago District

C. F. W. RYS,
Chief Metallurgical Engineer

Right

SYDNEY DILLON,
Chief Engineer

W. C. OBERG,
of Operations Pittsburgh
District

R. B. SAYLOR,
Assistant Manager of Operations
Pittsburgh District

J. A. HAGAN,
Chief Industrial Engineer

Right

C. R. MILLER, JR.,
Purchasing Agent, Pittsburgh

F. J. RIEF,
Purchasing Agent, Chicago

Right

CARROLL BURTON,
Vice President, Lorain Division

BENJAMIN F. FAIRLESS graduated from Ohio Northern University in civil engineering. He immediately went into steel making with the Central Steel Company, Massillon, Ohio.

He progressed through various departments of this company to the position of vice-president and general manager which he held until the company merged with the United Alloy Steel Corporation, Canton, Ohio. This new combine was named the Central Alloy Steel Corporation and Mr. Fairless subsequently became its chief executive.

In 1929 when Republic Steel absorbed this company, Mr. Fairless was made the executive vice-president. September 1935 found Mr. Fairless leaving this organization to accept the leadership of the newly organized Carnegie-Illinois Steel Corporation which has just been augmented by the addition of the American Sheet and Tin Plate Company.